



Experts Meeting

Conserving Concrete Heritage Experts Meeting

June 9-11, 2014

Meeting Report

Alice Custance-Baker and Susan Macdonald



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The Getty Center, Los Angeles, California

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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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Front cover: Le Corbusier. Concrete detail, the Assembly, Chandigarh, India, 1955.
Photo: Susan Macdonald, 2013.

The Getty Conservation Institute works 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.

Contents

Introduction	01
Conserving Concrete Heritage Experts Meeting Overview	02
Issues in the Conservation of Concrete Heritage	04
Potential Research to Advance the Conservation of Concrete Heritage	06
Creating and Disseminating Information to Fill Knowledge Gaps	15
Potential Education and Training Activities	19
Research Priorities	22
Conclusions and Next Steps	23
Proposed Action Plan	24
Appendix A: Participant Biographies	27
Appendix B: Participant Presentation Summaries	30
Appendix C: Background Paper	32
Appendix D: Meeting Agenda	44
Appendix E: Photographs of the Experts Meeting Discussion Boards	47

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 conservation and repair, 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 Overview

The Conserving Concrete Heritage Experts Meeting convened 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 some of the key players engaged in the conservation of concrete in modern heritage to examine the actions undertaken over the last two decades as a means of assessing the current state of concrete conservation in order to:

- identify potential research and other current needs;
- determine how to advance this area of material conservation;
- identify the priorities;
- identify entities able to progress these priorities;
- identify the scope of research on the conservation of concrete that the GCI could undertake and identify potential partners and stakeholders to work with in this area; and
- develop an action plan to implement the research and other activities.

Participants

Eight expert participants, considered critical thinkers and key players in the conservation and repair of concrete 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 have the potential to be influential in the future. The group comprised international practitioners working in this field, primarily from North America and Europe. This multidisciplinary gathering included engineers, architects, material scientists, educators, 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. It was organized around working sessions, with presentations from the invited participants, summaries of which can be found in appendix B. A background paper, “Conserving Concrete Heritage: An Experts Meeting to Identify Research Needs to Advance the Field,” was circulated in advance and presented on the first day of the meeting. The paper is found in appendix C. It outlined the state of the concrete conservation field and identified some of the issues faced by those involved in conservation. It also attempted to identify the areas where targeted research could provide potential solutions to these dilemmas. The background paper focused on the conservation and repair of exposed concrete, which is where the major conflicts between standard repair and conservation collide. It 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

In advance of the meeting, the GCI also prepared and distributed to participants 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.



Participants in the Conserving Concrete Heritage Experts Meeting. Photo: Getty Conservation Institute.

Issues in the Conservation of Concrete Heritage

During the meeting the participants identified 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 categorized in two groups: those who are highly knowledgeable about concrete, but have little or no knowledge of or interest in conservation, and those who are conservation professionals, but have little or no knowledge of or experience with concrete. In addition, the group agreed that it was important to reach beyond those who are looking for specific information in order to make information about concrete conservation more accessible generally, encouraging greater interest in and knowledge about the conservation of concrete heritage.

A wide range of issues and specific problems within the field of concrete conservation warrant attention and the development of solutions. These were grouped by activity type: 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.

Issues that could be addressed through research that would serve to advance the conservation of concrete:

- lack of detailed information on deterioration mechanisms affecting specific types of historic materials (i.e., concrete and reinforcement) and construction techniques, and related implications for their conservation and/or 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
- absence of agreement within the field on basic procedures/methodologies for concrete repair and conservation, oftentimes resulting in poor repairs
- effective repairs frequently alter appearance
- constant adaptation of repair products and the availability of independent information about their efficacy and use
- difficulty in identifying current research programs and efforts

Issues related to information gaps that could be addressed through the creation and dissemination of literature:

- lack of a robust body of literature on the conservation of concrete
- existing literature can be difficult to access
- need for material on concrete repair and conservation that is not produced by manufacturers or those with a vested interest
- the challenge of accessing the most useful and factually correct trade information given there is so much available
- lack of published case studies with detailed technical information on concrete conservation
- identifying the best places to publish to ensure that the information reaches the desired audience

Issues that could be addressed by or are related to education and training:

- insufficient respect for the craft skills
- shortage of concrete conservation experts (professionals with advanced knowledge in both conservation and concrete) internationally
- universities and technical colleges are generally uninterested in meeting the needs of a small, niche market such as concrete conservation
- lack of widespread qualifications, certification, or requirements for those working on conservation of concrete heritage projects
- difficulty determining where and how to deliver training to reach the correct audience
- concrete is not widely included in conservation course curricula
- limited qualified trainers are available to deliver courses to industry and conservation practitioners

Potential Research to Advance the Conservation of Concrete Heritage

The Getty Conservation Institute is well placed to undertake research to advance the conservation of concrete heritage, 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 as a specific 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. These include a lack of recognition for its material values and reluctance to apply the accepted conservation methodologies, levels of investigation, and diagnostic and repair approaches, all of which can be seen as more expensive than standard repair approaches. Shifting thinking to long-term repair and conservation solutions that incorporate long-term maintenance, and advancing knowledge of the many challenges facing the conservation of concrete, will lead to improved decision-making and informed choices for its conservation.

Research that would address a number of the issues that the group identified as priorities having the potential to 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 into past case studies as a means of understanding the efficacy of different techniques, approaches, and materials.

Investigation, Diagnostics and Analysis

Good conservation practice emphasizes work based upon a sound understanding of a structure's history, heritage significance, and physical condition, as well as current and potential risks. Therefore, access to tools and techniques that provide as much information as possible with the least physical impact to the structure is critical. Accurate and detailed investigation and condition assessment, generally using a variety of diagnostic tools, is essential to the process of identifying deterioration and developing conservation and repair proposals. Being able to predict, or at least understand, ongoing deterioration and the effect of any repair process is also critical to the development of conservation proposals. In many cases, 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

competent in both of these fields. Information currently available to practitioners for a number of the critical steps identified above is also limited.

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

Although there are increasing numbers of publications on historic concrete, information on the various types of concrete is scattered and informal, and rarely gets to the level of detail necessary for conservation planning. Nor has it reached a level of maturity where patterns of deterioration and durability have been identified and related to specific concrete and concrete system types. The group agreed that there is a need to bring together existing information and new research on the material characterization of historic concrete as a basis for conservation work.

The group suggested that an atlas of concrete types and systems, including information on their historic constituent materials (e.g., binders, aggregates, and reinforcement) and how to recognize them, would be of great assistance. A further compilation of information on subjects such as different historic reinforcement types and material compositions, design, deterioration patterns, and cement types as well as major concrete systems from different periods (for example, the Hennebique system in the prewar period and Schokbeton postwar), would help practitioners undertaking assessments and diagnosis of buildings.¹ Coupling this information with results from materials analysis and the results of previous research on the typical deterioration problems of specific historic concrete types, would further benefit the field.

Materials testing laboratories are highly familiar with modern concrete samples; however they can misinterpret historic concrete samples due to a lack of knowledge of historic production techniques and materials. Research into historic concrete types and materials, and dissemination of results, could improve knowledge at testing laboratories, which in turn would assist decision making for conservation methods and materials.

A European team working under the REDMONEST project is recording the scope of concrete heritage within the region of study (which includes Spain, France, Belgium, and Italy).² Factors being recorded include the composition of the components and material characterization of structures (e.g., steel or iron, binders, and aggregates), date of construction, and construction specifics. One aim of this project is to demonstrate the size of the potential concrete conservation market to encourage interest in developing the field. Rolled out internationally, this project would improve not only the profile of concrete conservation, but also our understanding of the historic concrete built environment.

¹ For example it is understood that the source of iron used for the production of rebar in the United States 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 later source. A group from the Docomomo International Specialist Committee for Technology is currently investigating how to advance research on the conservation of Schokbeton.

² For a summary of the REDMONEST project background and aims see, European Joint Programming Initiative for Global Heritage and Local Change, “Factsheet #10,” (Rome: JPICH, 2014), <http://www.heritageportal.eu/Browse-Topics/BUILT-HERITAGE/Factsheet-10-REDMONEST-Monitoring-Dynamic-Network-for-Existing-Structures-of-Concrete-Cultural-Heritage.pdf> (accessed January 6, 2015).

Another difficulty is identifying relevant research that has already been completed or is currently underway. Due to the large scale of the concrete field and lack of specific outlets for publishing research on concrete conservation topics it is not easy to locate this information. A centralized database for logging research would therefore be of benefit.

Development of diagnostic tools that improve understanding of deterioration with minimal impact on the structure

The group recognized a need for research into new and improved diagnostic tools to enhance accuracy, reduce physical impact on historic fabric, and improve the ability to predict the long-term behavior of historic concrete.

Where structural reinforcement is present, it is essential to be able to establish its location, quantity, and condition. Arguably, 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 research need identified by the group 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 its rate of development are current goals for the improvement of such technologies. In theory, radar could provide information on the condition of the concrete-steel interface, which controls corrosion behavior, but we do not yet have the technical capability to do this. The development of battery-operated sensors provides an opportunity for long-term monitoring of the development of corrosion, however, a method for attaching the sensors without compromising the historic fabric needs to be developed.

Enhanced ability to map the presence of moisture within concrete would greatly assist the field. 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 ingress.³

Long-term monitoring is required to track the structural condition of a building; therefore, the expert group was keen to promote research and development that could enable a more rapid assessment of structural movement. In combination with this, the development of technologies and information that could improve the ability to predict failures would be useful. One suggestion is to create a system that enables users to input new data into the standard failure prediction models to improve their accuracy.

Conservation and 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 repairs. The group identified a number of specific areas, which are discussed below.

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

Improved knowledge on the life cycle of concrete repairs and the role of maintenance

The outcomes of concrete repair and conservation works to historic buildings over the last few decades can inform current practice, but information on such projects is largely unharnessed and does not assist in assessing the long-term effectiveness of the methods used. There is little information on the life span of various repair methods, as monitoring and evaluation of concrete repair or conservation work is rare. Although it is recognized that most repair solutions will not be permanent and reinforced concrete will continue to decay over time, repair work is undertaken with the understanding that with minimal further intervention the service life of the structure will be extended for a reasonable period of time. 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, thus delaying larger scale intervention. However, 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 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, therefore patch repair of concrete is an integral part of any repair and conservation project. Despite this being the most common repair technique, there is widespread disagreement within the industry on some basic parameters for undertaking such repairs. With this level of disagreement, it is not surprising that a large number of concrete patches appear to fail within the relatively short time frame of ten to twenty years.⁴ This figure is likely to be relevant for conservation projects as well as the concrete industry at large.

The first stage in undertaking a patch repair is to remove the deteriorated concrete and prepare the area for the repair. Group discussions indicated that in the United States it is standard for patches to be undertaken with a straight geometry; this is not generally the case in Europe, although there is some crossover. The argument given for a straight geometry is that reduced boundary edge length and simple edge conditions result in less shrinkage stress concentrations and cracking, however it may require the removal of larger amounts of historic concrete. As the aim of conservation is to save as much historic fabric as possible, this could be an important area for further research.⁵

Current standards for removal of corroded reinforcement and splicing in new rebar are an associated issue. These specify a certain level of overlap with the

⁴ “Some 230 case-histories were obtained for concrete structures up to 150 years old but mostly 20 to 50 years old... Patches were applied in 60% of the repairs and were 30% successful when applied solo and 50% successful when applied in combination with a coating.” G.P. Tilly and J. Jacobs, *Concrete Repairs: Performance in Service and Current Practice* (Bracknell, UK: IHS-BRE Press, 2007), 8.

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

original rebar; this can necessitate removal of additional amounts of historic fabric. These requirements could be investigated to determine whether a reduction in overlap without compromising structural performance is possible under certain circumstances.

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 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 microcracking in the surrounding area.⁶ Repair product manufacturers specify that the prepared surface must be “clean” prior to application of the patch material, but there are no parameters for determining what clean means.⁷ 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 dampened 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 disagreements, reduce confusion, and reinforce the need to develop patch repair standards.

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 Research Laboratory for Historical Monuments (LRMH) found this method to be ineffective, with areas in which the technique was successful retaining their heightened pH for only two years or so.⁸

However, it was argued during the experts meeting that other studies have found this technique to be successful and there is a large amount of ongoing 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 projects, as well as a literature review that identifies key pieces of research and evidence for and against the success of this process.⁹

⁶ This issue, among others, is being addressed as part of the European REDMONEST project.

⁷ This pertains to concrete surfaces. Note: there is a Swedish standard for the surface cleaning of steel in relation to structural steel sections (e.g. I-beams), quoted as standard performance requirements (eg.SA2, SA2.5, SA3).

⁸ Emmanuel Cailleux, Élisabeth Marie-Victoire, M. Bach, F. Feugeas, and A. Cornet. “Treatment of Precorroded Steel Reinforcement by Surface-applied Corrosion Inhibitors: Solution Tests and Application to Concrete Samples.” In *Concrete Solutions: Proceedings of the Second International Conference on Concrete Repair, St. Malo, France, 27-29 June 2006*, edited by Michael Grantham, Raoul Jauberthie and Christophe Lanos (Watford, England: BRE Press, 2006), 619-28.

⁹ High-profile projects where the realkalization technique has been used include the Hoover Building (1938) and Uxbridge Station (1904), both in London.

Cathodic protection

Cathodic protection (CP) is generally considered the most comprehensive means of preventing corrosion of reinforcement. However, its application to historic concrete buildings has been limited. It is physically destructive, often visually disruptive, and it can be challenging to design 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 means of preventing the loss of historic fabric when embedding the anodes.

Because CP is an active system, maintenance is required; the necessary level of maintenance was debated by the group. There is also some question as to whether a “halo effect” exists, whereby an area surrounding that being treated by CP is negatively affected. Opinions differ. This could be a worthwhile topic for further research.

When concrete is affected by chlorides, cathodic protection is frequently the only recommended conservation technique. It is important to further develop this method to make it more compatible with conservation needs.

Corrosion inhibitors

Corrosion inhibitors have been successful in a limited number of situations, so the number of buildings on which they can be used is very small. In addition, migratory corrosion inhibitors need to be applied to a clean surface, which would necessitate the removal of or damage to any surface patina. For these reasons this field was not identified as one to be pursued as a priority by the group.

Repair Materials

Patch repair materials

In addition to the need for improved understanding of the patch repair process, there is a 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.¹⁰ Research into the characteristics and performance parameters required for successful repair materials 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 developing appropriate tests for selecting grouts for use in conserving architectural surfaces may be a useful model for development of tests for the selection of concrete repair mortars.¹¹ Studies could identify important metrics for repair materials and identify relevant test procedures such as those

¹⁰ The Concrete Repair Network (CONREPNET) project touched upon this issue, finding that the objective of some concrete repair material manufacturers was to ensure that no more than 50% of their product range was more than 3 years old. S. Matthews, M Sarkkinen, and J Morlidge. *Achieving durable repaired concrete structures: Adopting a performance-based intervention strategy*, CONREPNET Project Report EP77, (Berkshire, UK: IHS-BRE Press, 2007), 7.

¹¹ Information on the GCI project, Injection Grouts for the Conservation of Architectural Surfaces: Evaluation and Treatment, is available at http://www.getty.edu/conservation/our_projects/field_projects/grouts/index.html (accessed January 5, 2015).

detailed in BS EN 1504, *Products and Systems for the Protection and Repair of Concrete Structures*.¹²

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 desirable or feasible. New concrete can 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 there is a lack of 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 developed, providing guidelines for preserving or replicating different surface characteristics.

Standards for mortar specifications vary internationally. The European Union standard (EN 1504) results in specified special mortars being available only in large volumes. Manufacturers will not produce small quantities of these mortars because of the time and expense of getting European Conformity certification. For this reason it is common for people to use pre-bagged mortars, which may not be optimal for conservation projects. In the European Union, mixing on site will preclude a warranty, which may not be acceptable. In the United States, manufacturers are able to supply small quantities of specified mortars, so use of pre-bagged materials on heritage structures is less common. 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 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 ingress plays in reducing reinforcement corrosion. There are a number of concerns with the use of hydrophobic treatments that are important to highlight in terms of conservation and that any research needs to address, including:

- depth reached by penetrating hydrophobic treatments into the concrete;
- percentage concentration of product that achieves the desired result and penetrability;
- lack of reversibility;
- need for regular retreatment;
- future limitations for retreatment using alternative products;

¹² British Standards Institution, *Products and Systems for the Protection and Repair of Concrete Structures. Definitions, Requirements, Quality Control, Evaluation of Conformity. General Principles for Use of Products and Systems*. 2nd ed. BS EN 1504-9:2008 (London: British Standards Institution, 2009).

- 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, 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 investigation into their successful use on concrete. In addition, most of the products on the market have been developed for modern concrete and may not be compatible with historic concrete, which may have a more open pore structure. Alternative products may need to be developed for historic concrete.

There is a long history of the use of hydrophobic treatments on concrete heritage structures, particularly by the transportation industry on bridges. This provides an opportunity to assess the current condition of these structures to determine whether any of the above concerns are in evidence. A literature review documenting past and present uses of these treatments would assist specifiers in selecting appropriate products. Further research and development of hydrophobic treatments should consider all of the points raised above. In addition, development of a nondestructive method for effectively measuring the success of a treatment would greatly benefit the field.

The group noted with interest that ongoing research under the European REDMONEST project is currently 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, but because it has been identified in many nuclear facilities, there is already 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; this is a potential area for further research. Given that ASR has not been identified as a major cause of problems for historic concrete buildings, it was agreed that this is not a priority.

Consolidants are more commonly used on stone but they may have some use on concrete, particularly in the case of sculptural elements. Most of the known research has been conducted on stone. There appears to be 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.

Early in the discussions, crack fillers were identified as an important feature of concrete conservation and repair, however the group did not consider this to be one of the key topics requiring further discussion.

Case Studies

It was agreed that reassessment of past conservation and repair projects on historic concrete buildings would be a major source of information for the development and improvement in our understanding of conservation treatments. There are many

potential challenges with this form of research, including a lack of documentation. It can be difficult to identify 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. Furthermore, obtaining the necessary information on materials and techniques used can be challenging, and it was agreed that there might be some resistance to the reassessment of conservation works that might be construed as failures.

Participants agreed that a framework for the reassessment of conservation or repair work on concrete structures would enhance the usability of the data collected. Developing a template for evaluation of past projects and work undertaken, as independent research to assess the efficacy of approaches and techniques, would foster more accurate results. Such evaluations could commence with simple visual assessment, then move to more detailed analysis using test techniques and methods.

Creating and Disseminating Information to Fill Knowledge Gaps

A draft version of *Conserving Concrete Heritage: An Annotated Bibliography* was distributed to meeting participants in advance of the experts meeting in an effort to inform the discussions. This forthcoming publication is organized in 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
5. Conservation and Repair of Historic Concrete

The annotated bibliography aims to bring together the key English-language texts specific to concrete conservation. A limited number of vital texts from the concrete repair industry were included due to the importance placed upon them within the broader concrete industry. One of the purposes of this bibliography is to identify the gaps in the literature in order to inform future research and potential publications. The bibliography will be further developed and made available for download on the GCI website in 2015. It will be updated periodically.

Existing Concrete Literature

At present, there are many gaps in the literature on the conservation of concrete and it is often difficult to locate or access. In contrast, there is a vast body of published work on concrete repair, which can be difficult to navigate for those from a conservation background who are new to concrete and concrete repair. In addition, much of this work has been produced by the concrete industry and manufacturers, making it extremely difficult to separate publications that are truly independent from those that are biased towards industry approaches and products. There is also a body of published academic research on concrete. However, given the broad scope of this work it is difficult to identify the research underway that is of relevance to conservation.

Many of the best guides to concrete conservation in the English-speaking world and France come from government heritage bodies (the group did not have knowledge of publications available in other languages). However, these are fairly introductory, having been developed largely when concrete buildings were just

beginning to gain protected status. They were intended to cover basic information and do not provide the level of detail necessary for undertaking a concrete conservation project. The French Research Laboratory for Historical Monuments (LRMH) guidance documents are an exception, getting into a very useful level of technical detail.¹³ Translation of these into English and other languages would provide wider access to this information.

Ideas discussed at the meeting as valuable 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, revision of pertinent but out of date publications, and translations of useful publications to increase dissemination internationally. This final point is important because there are many regions of the world with large concrete industries, but the language barriers make sharing information difficult.

Glossaries

Although there are separate glossaries of terms for the conservation field and concrete repair industry, there is no known glossary specific to concrete conservation. This could be a meaningful contribution to the field and such a glossary could perform a similar role to the ICOMOS-ISCS *Illustrated Glossary on Stone Deterioration Patterns*.¹⁴ As an alternative to the production of an entirely new glossary, concrete conservation terms could be added to new editions of the current glossaries from the concrete repair industry. Publications from other organizations and programs, such as the American Concrete Institute and the Concrete Repair Network (CONREPNET), could also be drawn from in developing such a resource.

Technical Guidance Notes

Technical guidance notes for concrete conservation would be a very useful resource, particularly for people who are 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. Guidance notes could be aimed at building owners, contractors, or professionals; each audience may require a different level of information. Frequently, building owners select the project contractor or engineer. A set of

¹³ These include, Élisabeth Marie-Victoire. *Les altérations visibles du béton: définitions et aide au diagnostic*. Les Cahiers Techniques du Cercle des Partenaires du Patrimoine 1 (Champs-sur-Marne: Cercle des Partenaires du Patrimoine, 1996); Myriam Bouichou and Élisabeth Marie-Victoire. eds. *Le nettoyage des bétons anciens. Guide des techniques et aide à la décision*. Les Cahiers Techniques du Cercle des Partenaires du Patrimoine 4 (Champs-sur-Marne: Cercle des Partenaires du Patrimoine, 2009).

¹⁴ Véronique Vergès-Belmin, ed. *Illustrated Glossary on Stone Deterioration Patterns. Glossaire illustré sur les formes d'altération de la pierre* (Champigny-sur-Marne, France: ICOMOS-ISCS, 2008).

http://www.icomos.org/publications/monuments_and_sites/15/pdf/Monuments_and_Sites_15_ISCS_Glossary_Stone.pdf (accessed January 7, 2015).

guidance notes geared toward their interests could help them form qualified teams at the start of a project.¹⁵

Guidance notes could take a number of forms. One suggestion was for notes that simply identify five or six parameters to look for on product technical data sheets, providing sufficient detail to assist with material specification. Another suggestion was a simple set of notes highlighting the different stages of a concrete conservation project. Developing publications that detail the role of maintenance of concrete buildings was also identified as a specific area of need. It was recognized that preparation of such information necessitates research work. Given current debates on a number of the processes involved, this is a larger task than simply repackaging existing information.

Case Studies

Encouraging the publication of case studies that include detailed technical information about the work undertaken was identified as a very-useful, short-term activity. In addition to this, technical reevaluations of conservation and repair work would be highly beneficial to improve understanding of past successes and failures 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.

Other Resources

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

Some specific research and publication projects 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;
- publications, including case studies, on older conservation/repair methods that are known to be inappropriate (e.g., epoxy coatings), which may discourage practitioners from using them;
- case studies that explain investigative and analytical work to diagnose problems and the development of repair solutions;
- addendums to currently available material in the concrete repair industry (e.g., the American Concrete Institute (ACI) *Concrete Repair*

¹⁵ An example of such a publication, though not geared toward conservation, is: International Federation for Structural Concrete, *Concrete Structure Management: Guide to Ownership and Good Practice*. FIB Bulletin 44 (Lausanne: International Federation for Structural Concrete, 2008).

Manual), which could be incorporated into existing materials or published separately; and¹⁶

- contribution to an owner's guide already in production as part of the ACI's "Vision 2020" project or adapting and developing earlier owner's guides, such as those by the International Federation for Structural Concrete and the Building Research Establishment.¹⁷

It is important to identify the best places to publish to ensure that information reaches the desired audience. The group noted that integration of conservation-related material into broader technical literature is of high importance. While the conservation industry is fairly contained and targeted information is relatively easy to promulgate, the general concrete repair industry is vast and delivering targeted conservation information to this audience is far more challenging. The electronic newsletters and bulletins regularly produced by the concrete industry provide a potential avenue through which conservation issues and needs could be efficiently introduced to a wide audience.

¹⁶ Mark E. Hughes and Carl R. Bischof. *Concrete Repair Manual*, 4th edition (Farmington Hills, MI: American Concrete Institute, 2013).

¹⁷ International Federation for Structural Concrete, *Concrete Structure Management*; Stuart Matthews and Josse Jacobs. *Concrete Structure Management: Owner's Guide to Good Practice*. Digest 510 (Garston, Watford: IHS BRE Press, 2009).

Potential Education and Training Activities

The first consideration in developing concrete conservation education and training activities is to correctly identify the audience. Generally, 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. It can be further divided by profession, contractors and specifiers broadly, and more specifically laborers, site supervisors, engineers, architects, manufacturers, and so on. Building owners, who may have little knowledge of concrete, are another important audience. Once the target audience is identified, where and how to deliver training are important considerations.

Training Needs by Audience

The group discussed various training audiences, their different requirements in terms of the level of theoretical and practical training, and the correct training environments.

Architects and engineers

The majority of training for architects and engineers, particularly in the United States, focuses on new design and does not emphasize what happens after the concrete has been placed. In many countries there are regulations or certification requirements for architects or engineers authorized to 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.

Specifiers, who are generally architects or engineers, require a good understanding of the complexities involved in both concrete repair and concrete conservation. They need to consider the effect that repairs will have on a structure physically, chemically, and aesthetically. It is essential that this group understand not just how things are done in a certain way, but also why.

The often poor quality of condition assessments prior to the commencement of work was one of the issues brought up for discussion. The expert group felt that condition assessments must be a major focus of training, as they are the backbone for all decision-making. Another important thing for specifiers to be able to identify is when they are at the limit of their knowledge and need to bring someone with greater experience onto the project, including at the condition survey stage. They should also be able to identify the difference between good and poor repairs, so they can supervise projects knowledgeably.

Specifiers who are architects or engineers require continuous professional development to retain their certifications or licenses. This provides an excellent

opportunity to offer education and training courses that reach professionals who have not had previous training in concrete repair.

The American Concrete Institute's recently released concrete repair code, ACI 562-13 (expected to soon be integrated into United States and perhaps international building codes) will encourage training and education, and will create incentives and requirements for professionals to improve their knowledge in overall concrete repair.¹⁸ The challenge to the conservation community will be to develop strategies to help move that to the next level of conservation.

Contractors and craftspeople

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

A meeting participant cited a two-day training program for contractors that is currently delivered in Belgium as a potential model for training programs internationally. The program's first day is half theory and half practical. During the second day, participants must undertake a patch repair on which three checks are made to determine whether it is flat, whether there are cracks, and the strength of the adhesion. The training is provided by the Federation of Repair Contractors.

Non-specialists

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

Training strategies

The group agreed that the goal is to work towards the integration of concrete conservation training within standard concrete industry training, rather than as a separate track. One barrier to education and training in concrete conservation is that the industry is perceived to be too small to warrant university and technical college investment. Furthermore, concrete conservation tends to receive little attention in the majority of conservation course curricula, most likely because it is a relatively new area of conservation, but also due to the dearth of experts available to provide such training.

Meeting participants cited trade shows, such as the annual World of Concrete, as opportunities to reach a huge segment of the concrete repair industry audience. Another avenue might be working with concrete industry bodies, such as the

¹⁸ This new building code applies within the United States to structural design considerations for concrete structures, particularly in terms of life safety. Adherence to the code will be mandatory by any city, county, or state that chooses to adopt it as part of their overall code requirements. ACI Committee 562. *Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary* (Farmington Hills, MI: American Concrete Institute, 2013).

American Concrete Institute and International Concrete Repair Institute, to develop interest and training programs. These two groups are already working together to produce an online training program for concrete repair, and there could be an opportunity to include conservation within this program. Training in concrete conservation for practitioners could be offered at the annual conferences of such bodies as the Association for Preservation Technology International, American Institute for Conservation of Historic and Artistic Works, and the Institute of Conservation. Developing short training modules and didactic materials for use by trainers was identified as a useful way forward.

Qualifications and certification are a potential means of improving project team member selection. Certification through professional bodies may be the best approach. It appears that steps have been taken towards a European certification, presently limited to individual countries (for example the Belgian training program previously highlighted). There is already some movement toward certification for concrete repairs by industry bodies, but it is up to specifiers to identify the requirements for contractors and to ensure that qualified people are hired, which should be encouraged and promoted.

There are existing concrete education programs at the university and technical college level and there may be potential for the conservation community to engage with these programs. One example is the Concrete Industry Management (CIM) program, which offers Bachelor of Science degrees at four universities across the United States; the CIM curriculum requires completion of an upper-division course on concrete repair. The CIM program at California State University, Chico, cooperates with the Concrete Preservation Institute (CPI)'s Preservation Field School to provide an opportunity for their students to gain further specialized training in concrete conservation.

CPI is a nonprofit educational foundation that partners with the National Park Service and the Golden Gate National Parks Conservancy on Alcatraz Island. CPI bridges professional exposure and student training in concrete conservation by providing hands-on training and research in concrete conservation to college students, high school graduates, military veterans, and practicing professionals at Alcatraz.

Catalog of Training Programs

Meeting participants identified creation of a database or list cataloging training programs currently offered to different sectors of the industry as a fruitful first step in advancing training and education activities. This would promote understanding of the scope of existing work and delivery modes, and the organizations involved, facilitating development of new and improved programs.

Research Priorities

The expert group was asked to identify what they considered to be the top research priorities for the field, both short-term actions that could be undertaken relatively easily and quickly for 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 highest priorities were patch repair methods and materials, and penetrating hydrophobic treatments (silanes). In the short term, a literature review of each of these topics was proposed as a means of improving understanding of the current state of these fields and identifying knowledge gaps, which could lead to additional research programs.

Long-term research identified for patch repairs focused on the need for guidance on how to undertake a successful patch repair (including defining what is meant by successful) and on the appropriate specification of materials for such repairs. This work would be heavily influenced by the results of the literature review and would require significant laboratory and on-site studies. Long-term research prioritized for penetrating hydrophobic treatments included the assessment of past treatments. In addition the group was keen to discuss and collaborate on the development of available treatments with manufacturers.

Two other priority areas of research were the evaluation of past conservation treatments and characterization of historic concrete. The group recognized that both will be difficult to achieve and will require a concerted research effort. The reevaluation of past conservation treatments, which is essential to understanding which treatments are successful and which are not, poses several challenges. This work will rely heavily on documentation from when treatments were implemented. Additionally, identifying success or failure is very subjective. Furthermore, obtaining sufficient detail will require small-scale destructive testing of materials.

The characterization of historic concrete, which could aid the assessment and understanding of material interactions that occur in historic concrete structures, also poses challenges. This research will 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 underway in the fields of moisture monitoring, nondestructive testing, and realkalization.

Conclusions and Next Steps

Following the experts meeting, the GCI summarized the actions identified and prioritized at the meeting, then developed a proposed action plan, which outlines potential work to advance the field. The action plan appears below. Potential actions are organized within the categories used at the meeting, although the GCI recognizes that there is overlap between these categories. For each activity, desired outcomes or impacts are identified, specific outputs or products are proposed, and potential actors discussed at the meeting are listed.

This report on the meeting's outcomes will be made available online and will be circulated to potentially interested parties. Feedback will be sought on the ideas contained herein.

The expert meeting identified a number of potential actions that would advance the conservation of concrete in the short, medium, and long terms. The GCI intends to investigate these options and develop its own program of research and other related activities in 2015. Inevitably, and consistent with the typical GCI approach, this work will be undertaken with other organizations. It is not the GCI's intention to tackle all of these actions, some of which may be better pursued by other entities.

In the immediate future, the GCI will finalize *Conserving Concrete Heritage: An Annotated Bibliography*, and make it available as a free online resource. A publication series addressing case studies on the conservation of modern heritage has recently been initiated with the first volume to cover case studies on the conservation of concrete buildings and structures. This publication project commenced in late 2014.

Proposed Action Plan

	Short-term actions that could be undertaken simply and relatively quickly.
	Long-term actions that would require a concerted and sustained effort.

POTENTIAL RESEARCH TO ADVANCE THE CONSERVATION OF CONCRETE		
Action: Undertake a literature review on the use of hydrophobic treatments on concrete		
Desired outcome <ul style="list-style-type: none"> Synthesis of information on the use of hydrophobic treatments in concrete conservation and repair, which will assist in determining where further research may be of benefit 	Output <ul style="list-style-type: none"> Literature review 	Potential actors <ul style="list-style-type: none"> Universities – Columbia GCI
Action: Undertake a literature review on concrete patch repair methods and materials		
Desired outcome <ul style="list-style-type: none"> Synthesize information on concrete patch repair methods and materials to assist in determining where further research may be of benefit 	Output <ul style="list-style-type: none"> Literature review 	Potential actor <ul style="list-style-type: none"> GCI
Action: Conduct research on the material characteristics of historic concrete and its constituent materials, and implications for conservation		
Desired outcomes <ul style="list-style-type: none"> Improved information on historic concrete types and how to recognize them Improved ability to correlate knowledge about how different types of concrete decay, conservation issues, and responses Better analysis of historic concrete by testing labs 	Output <ul style="list-style-type: none"> An atlas of concrete types and their constituent parts 	Potential actors <ul style="list-style-type: none"> Heritage agencies Universities Industry GCI
Action: Develop improved nondestructive tools for assessing the condition and rate of corrosion		
Desired outcomes <ul style="list-style-type: none"> More accurate information on the location, extent, and rate of corrosion to better develop conservation and repair approaches Reduce the use of destructive techniques 	Output <ul style="list-style-type: none"> New/improved tools 	Potential actors <ul style="list-style-type: none"> Industry—equipment manufacturers Industry organizations (e.g., ICRI, ACI) Universities
Action: Develop/enhance 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 	Output <ul style="list-style-type: none"> New/improved tool for NDT 	Potential actors <ul style="list-style-type: none"> Industry—equipment manufacturers Industry organizations (e.g., ICRI, ACI) Universities
Action: Conduct research, using defined standards, to evaluate the life-cycle of key conservation and repair types		
Desired outcomes <ul style="list-style-type: none"> Agreed-upon methodology for evaluating repairs Better understanding of the service life of conservation and repair options Improved ability to determine life cycle of repairs and evaluate conservation and repair options 	Outputs <ul style="list-style-type: none"> Template for evaluation of repairs Data on service life of conservation and repair options and life cycle 	Potential actors <ul style="list-style-type: none"> Industry Universities Research institutes Building Research Establishment (BRE)

POTENTIAL RESEARCH TO ADVANCE THE CONSERVATION OF CONCRETE (CONT.)		
Action: Conduct research that facilitates the development of standards for concrete patch repair		
Desired outcomes <ul style="list-style-type: none"> • Knowledge about best practice for undertaking patch repair that meets conservation requirements, including recommendations for cutting out, placement, and reinforcement repair • Clear understanding of good practice and elimination of confusion and contradictions 	Output <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 organizations (e.g., ICRI, ACI)
Action: Develop parameters for the selection of appropriate repair mortars for patch repairs that address regional/country standards		
Desired outcome <ul style="list-style-type: none"> • Improved knowledge on appropriate materials and selection criteria for repair mortars 	Output <ul style="list-style-type: none"> • Guidance on specification of appropriate repair mortars for concrete conservation 	Potential actors <ul style="list-style-type: none"> • GCI • Industry
Action: Evaluate past repairs using specific techniques including realkalization, cathodic protection, and desalination		
Desired outcome <ul style="list-style-type: none"> • Improved knowledge about the performance of past repair processes and systems to historic buildings (e.g., realkalization, CP) 	Outputs <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 	Potential actors <ul style="list-style-type: none"> • Universities • GCI • Industry • Practitioners
Action: Further develop cathodic protection systems for heritage conservation projects		
Desired outcome <ul style="list-style-type: none"> • Potential to use CP with reduced physical and visual impact to historic buildings 	Output <ul style="list-style-type: none"> • Improved CP systems for heritage conservation 	Potential actors <ul style="list-style-type: none"> • Industry • Universities • Heritage agencies/ research institutes
Action: Develop methodologies for replicating existing surface finishes		
Desired outcome <ul style="list-style-type: none"> • Shared understanding of how to replicate historic surface finishes during conservation and repair works 	Output <ul style="list-style-type: none"> • Guidance document on replicating historic surface finishes 	Potential actors <ul style="list-style-type: none"> • GCI • Industry • Universities

CREATING AND DISSEMINATING INFORMATION TO FILL KNOWLEDGE GAPS		
Action: Complete and publish <i>Conserving Concrete Heritage: An Annotated Bibliography</i>		
Desired outcome <ul style="list-style-type: none"> • Improved access to and knowledge about currently available information on concrete conservation 	Outputs <ul style="list-style-type: none"> • Online publication • Index of organizations engaged in concrete repair and conservation 	Potential actor <ul style="list-style-type: none"> • GCI
Action: Compile glossary of terms including definitions of deterioration mechanisms		
Desired outcomes <ul style="list-style-type: none"> • Improved understanding of the deterioration mechanisms for historic concrete • Alignment of terminology for practitioners across conservation and repair sectors 	Output: <ul style="list-style-type: none"> • Illustrated glossary 	Potential actors <ul style="list-style-type: none"> • GCI • LRMH • Industry • BRE
Action: Document case studies, and share experiences and knowledge from conservation projects		
Desired outcome <ul style="list-style-type: none"> • Access to information on approaches and strategies for the conservation and repair of concrete heritage 	Output <ul style="list-style-type: none"> • Case study publication on concrete conservation (first in a series on modern materials) 	Potential actor <ul style="list-style-type: none"> • GCI
Action: Draft technical guidelines on a number of identified conservation and repair processes and techniques		
Desired outcome <ul style="list-style-type: none"> • Improved understanding and quality of conservation work 	Output <ul style="list-style-type: none"> • Suite of guidance documents targeted to conservation audience 	Potential actors <ul style="list-style-type: none"> • Heritage agencies • GCI • Industry • BRE
Action: Create an illustrated guide to conservation practice for practitioners		
Desired outcome <ul style="list-style-type: none"> • Improved understanding of conservation 	Output <ul style="list-style-type: none"> • Illustrated guide 	Potential actors: <ul style="list-style-type: none"> • Heritage agencies • GCI

CREATING AND DISSEMINATING INFORMATION TO FILL KNOWLEDGE GAPS (CONT.)		
Action: Integrate conservation approaches and methods into industry standards and guidelines		
Desired outcome <ul style="list-style-type: none"> • Conservation needs will be better understood and included in general repair information 	Outputs <ul style="list-style-type: none"> • Industry standards guidance includes conservation needs, and methods • Include conservation in ACI's Vision 2020 owner's guide 	Potential actors <ul style="list-style-type: none"> • Industry (e.g., ICRI, ACI) • Conservation bodies • Heritage agencies • GCI

POTENTIAL EDUCATION AND TRAINING ACTIVITIES		
Action: Develop list or database of training activities in concrete repair and concrete conservation		
Desired outcomes <ul style="list-style-type: none"> • Knowledge of existing training activities: where, who provides it, and what is covered • Gaps and potential to fill them identified 	Output <ul style="list-style-type: none"> • Reference list of training outlets 	Potential actors <ul style="list-style-type: none"> • GCI • Industry (e.g., ICRI, ACI)
Action: Develop basic concrete conservation training module for conservation practitioners		
Desired outcome <ul style="list-style-type: none"> • Improved understanding of the conservation of concrete by conservation practitioners 	Output <ul style="list-style-type: none"> • Training module and didactic materials 	Potential actors <ul style="list-style-type: none"> • APT • Conservation bodies • Industry • GCI • Universities • BRE
Action: Develop basic conservation training module for concrete repair industry		
Desired outcome <ul style="list-style-type: none"> • Improved understanding of the conservation of concrete by the concrete repair industry 	Output <ul style="list-style-type: none"> • Training module and didactic materials 	Potential actors <ul style="list-style-type: none"> • Industry (e.g., ICRI, ACI) • Conservation bodies (e.g., APT) • GCI • BRE

Appendix A: Participant Biographies

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 1990s, 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. Courard is a member of ACI, RILEM, and the Belgian Group of Concrete. He has authored or coauthored 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*. Custance-Baker previously worked as an architectural conservator for Nicolas Boyes Stone Conservation, Edinburgh, and as the building materials analyst at the Scottish Lime Centre Trust, Fife, United Kingdom. She received her BSc Hons and MSc by Research in geology from the University of Edinburgh and has undertaken a wide range of conservation training, including participation in the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) Seventeenth International Course on Stone Conservation.

David Farrell is the managing director of Rowan Technologies, a United Kingdom company that specializes in the development and application of new methods of conserving the fabric of historic structures and buildings. Farrell 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. He set up Rowan Technologies in 1991 to further his research and development ambitions. The company has been consultant to English Heritage since 1991 and has 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 nonhistoric reinforced and mass concrete structures, on churches, cathedrals, castles, fortifications, and monuments.

Tanya Komas holds a PhD in architecture (Texas A&M University) and degrees in historic preservation (Columbia University) and landscape architecture (University of California Davis). She is chair/professor of the Concrete Industry Management program at California State University, Chico, and Founding Director of the Concrete Preservation Institute that partners with the US National Park Service at Alcatraz Island to train and conduct research in concrete repair and conservation. Komas serves on the board of the International Concrete Repair Institute and was honored as one of “Five Most Influential People in the Concrete Industry” by *Concrete Construction Magazine* (2013).

Tom Learner is head of Science at the Getty Conservation Institute 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 to 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 she has worked with English Heritage, and in private architectural practice in the United Kingdom and Australia. Macdonald has written widely on twentieth-century heritage, including authoring and editing *Concrete: Building Pathology* (2002). 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 Research Laboratory for Historical Monuments (LRMH), a national public service linked to the architecture and heritage department of the French Ministry of Culture, for twenty years. She is a material sciences engineer and is in charge of the concrete department. She is working on identification, diagnosis, conservation, and restoration of historic concrete buildings and has authored a number of publications on this subject.

Stuart Matthews is chief engineer construction, and previously director of the Centre for Concrete Construction at the Building Research Establishment (BRE), United Kingdom. He is both a Chartered Engineer and a Chartered Scientist with a PhD in the dynamic behavior of cable-stayed bridge structures from Sheffield University, United Kingdom, and has been in practice for over thirty-five years. Matthews’ experience includes structural inspection, failure investigation, assessment, monitoring, and repair of existing structures. He was the coordinator for the CONREPNET European research project, which proposed a performance-based approach to the remediation of reinforced concrete structures for achieving durable repaired concrete structures. He currently convenes the International Federation for Structural Concrete, Commission 3: *Existing concrete structures*. Matthews was unable to attend the June 2014 experts meeting in Los Angeles, but provided comments on the draft report.

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 twenty-five years of experience in corrosion, electrochemistry and the repair of concrete and masonry structures. Professionally trained in electrical/electronic engineering, Noyce's groundbreaking work in electrochemistry includes realkalization, chloride extraction, electro osmosis, and the extensive use of ICCP on heritage structures. His recent work spans from landmark structures to the largest concrete repair projects in the United States, 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 forty 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. 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 Solomon R. Guggenheim Museum. He has taught at Columbia University since 1977. Weiss, a Fellow of the Association for Preservation Technology, is VP of MCC Materials, and director of scientific research of Integrated Conservation Resources. He is consultant editor of the *Journal of Architectural Conservation*, and vice chairman of the Preservation Technology and Training Board of the US National Park Service.

Appendix B: Participant Presentation Summaries

Luc Courard, University of Liège, Liège, Belgium

“Concrete Surface Engineering for Cultural Heritage”

Courard 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. 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, Manchester, England

“Surface Finishing Repaired or Cleaned Historic Concrete”

Farrell discussed two United Kingdom 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 (aka 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. Farrell discussed a range of trials undertaken. One method he is currently trialling is a cement wash used in a way similar to how a limewash is used, as a means to unify the surface in an essentially like-for-like repair by putting a cementitious layer back on the concrete.

Tanya Komars, Concrete Preservation Institute, California, USA

“Challenges, Decision Making, and Progress”

Komars presented on her work at Alcatraz Island, California, among other case studies, and her involvement in a degree program incorporating the conservation of concrete. She suggested that while the general focus is on the durability of the patch, the conservation industry should consider undertaking sacrificial repairs that can protect the surrounding historic fabric. One of Komars’ aims as an educator is to direct students away from liability decision making. She believes there would be a high value in quantifying the number of concrete structures that currently need conservation or will in the future as a means of generating interest in conservation within the concrete industry.

Paul Noyce, Axieom, New York, USA

“Challenges of Implementing Durable Repairs for Conservation”

Noyce 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 and Co, Missouri, USA

“Unique Challenges in Patching Historic Concrete”

Rewerts described practical conservation works that his firm had undertaken at Frank Lloyd Wright’s Unity Temple in Oak Park, 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”

Silman focused on his position as a consumer rather than a conservator, with a focus on desirable technologies for investigation and nondestructive testing for engineers. One particular request was to have a technology that could produce faster results 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 the Solomon R. Guggenheim museum in New York.

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

“Carbonation Induced Corrosion: A Main Conservation Issue”

Marie-Victoire 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, and conservation strategies. Despite carbonation being highly destructive, one benefit is that it is quite well understood as an issue.

Norman Weiss, Columbia University, New York, USA

“Concrete Carbonation Chemistry Cautiously (re-)Considered”

Weiss discussed the carbonation of concrete and what is and is not known, highlighting potential gaps or contradictions in the literature, such as whether or not carbonation produces 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 C: 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 the 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 thorough 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.¹⁹ 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.”²⁰ 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.²¹ *Vision 2020* specifically identifies the need to develop a

¹⁹ 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).

²⁰ *Ibid.*, 3.

²¹ 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/.

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 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 1912.²² 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*, 1979.²³ 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.²⁴ More have followed and there is now a modest body of literature in some parts of the world

²² 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).

²³ 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).

²⁴ 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).

on the historical development of concrete in all its forms, including more recent literature reviews that are enhancing our understanding of the material.²⁵

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 United Kingdom 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.

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.²⁶ 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.²⁷ Docomomo and APT both convened focused events on concrete conservation from the mid

²⁵ For example, Edwin A.R. Trout, *Some Writers on Concrete: The Literature of Reinforced Concrete, 1897-1935* (Dunbeath, Scotland: Whittles Publishing, 2013).

²⁶ Theodore H.M. Prudon, "Confronting Concrete Realities," *Progressive Architecture* 62, no. 11 (1981):131-37.

²⁷ 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).

1990s and published the outcomes.²⁸ 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.²⁹

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 conservation, as well as a number of case studies.³⁰ 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.³¹ However, it was not until the 2000s that dedicated books and guidelines on the subject began to be published.³²

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 2007.³³ In Australia and New Zealand, technical guidelines on concrete were also produced in the 2000s; other countries are beginning to publish guidelines as well.³⁴

In terms of dedicated programs on conserving concrete, perhaps the most specifically targeted is that of the French Research Laboratory for Historical Monuments (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.³⁵

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

²⁸ 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).

²⁹ 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).

³⁰ 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).

³¹ Adrienne Beaudet Cowden, *Historic Concrete: An Annotated Bibliography* (Washington, DC: National Park Service, Preservation Assistance Division, 1993).

³² 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).

³³ 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).

³⁴ 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).

³⁵ 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.³⁶

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.”³⁷

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 1989.³⁸ 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 a task group that is developing coordination efforts between ACI, ICRI, APT, and the Technical Research Board Committee on Historic and Archeological Preservation.

³⁶ Information provided by Elisabeth Marie Victoire, March 2014. *See also* www.gemme.ulg.ac.be/?q=redmonest-be2.

³⁷ Strategic Development Council, 19.

³⁸ 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).

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.³⁹

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 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

³⁹ 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.

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 D: Meeting 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,</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 six-minute presentation.</i> <ul style="list-style-type: none">• <i>Luc Courard, University of Liege, GeMMe Research Group</i>• <i>David Farrell, Rowan Technologies</i>• <i>Tanya Komar, Concrete Preservation Institute</i>• <i>Paul Noyce, Axieom</i>• <i>Thomas Rewerts, Thos. Rewerts & Co.</i>• <i>Robert Silman, Robert Silman Associates Structural Engineers</i>• <i>Elisabeth Marie Victoire, Research Laboratory on Historical Monuments</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</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

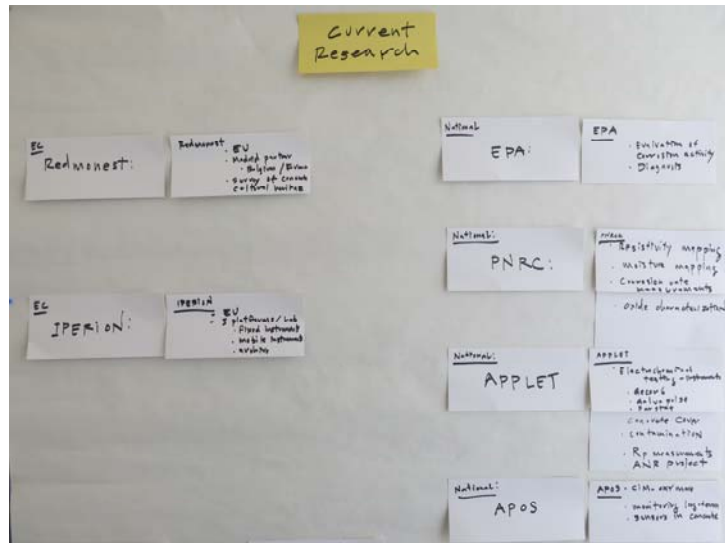
Wednesday, June 11, 2014

Location: Getty Center Board Room

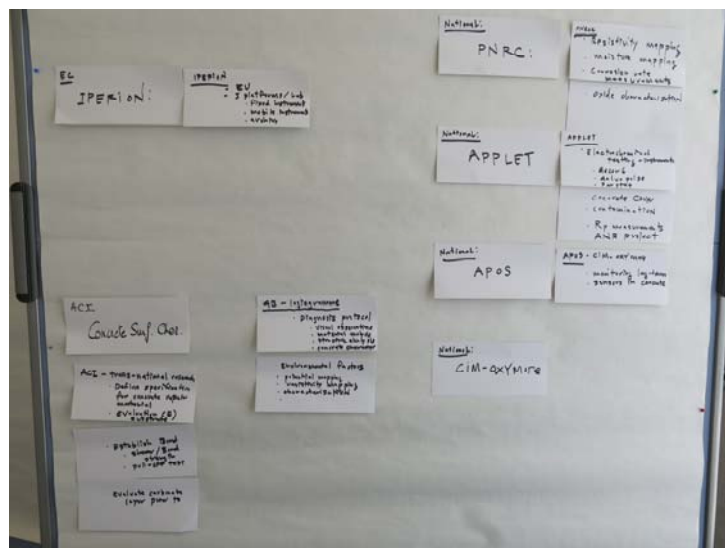
9:00 am – 9:15 am	Recap and discuss areas of research
9:15 am – 10:45 am conservation	Working groups: Discuss areas of research in concrete Each working group to develop work plans <ul style="list-style-type: none">• <i>Research (Boardroom)</i>• <i>Education and Training (Private Dining Room)</i>• <i>Publications—Literature 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	<i>Conserving Concrete Heritage: An Annotated Bibliography</i> <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 the Experts Meeting Discussion Boards

As a means for recording and developing discussions during the experts meeting key points were noted on boards kept around the meeting room as illustrated below.

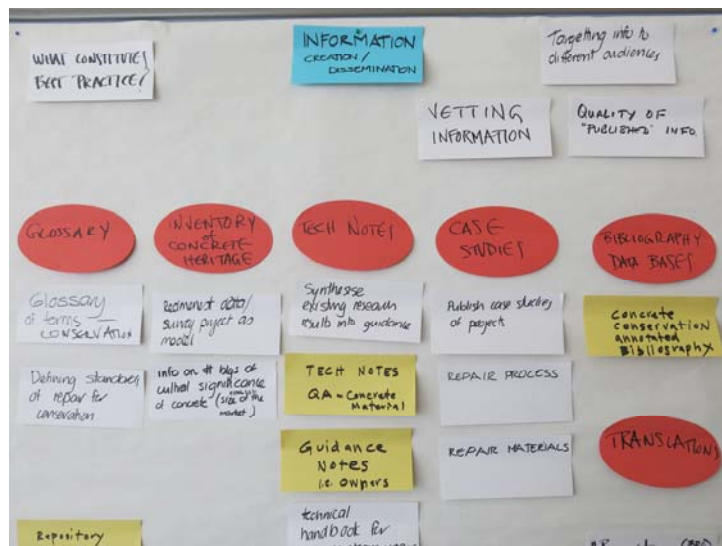
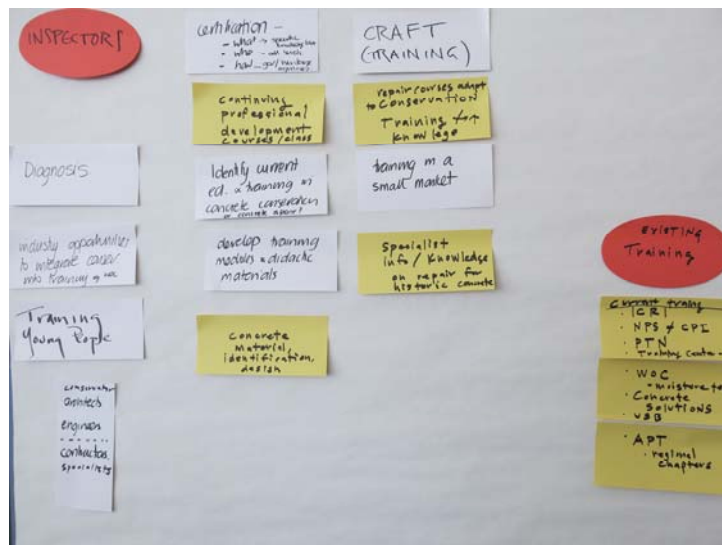


Known research currently underway





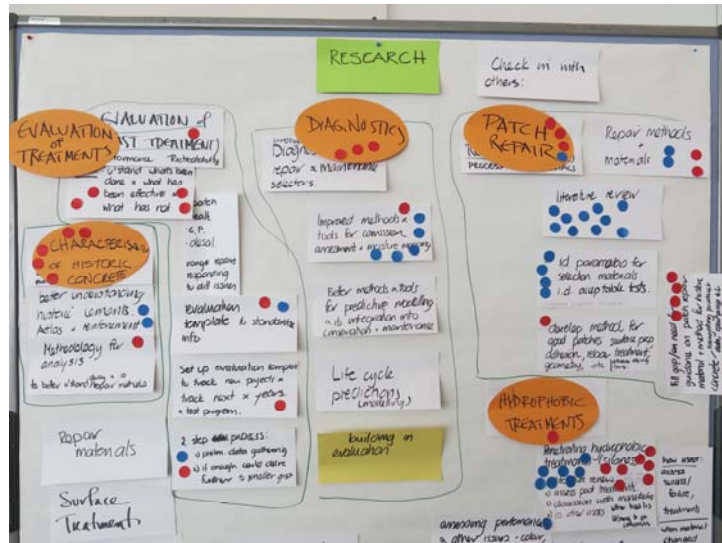
Areas of education and training identified and discussed



Information needs in the field of concrete conservation 1 of 2



Information needs in the field of concrete conservation 2 of 2



Key areas of research identified and discussed. The participants were asked to identify the topics that they felt would have the most impact on the field (red dots), and those, which would be both useful and easy to achieve (blue dots).



