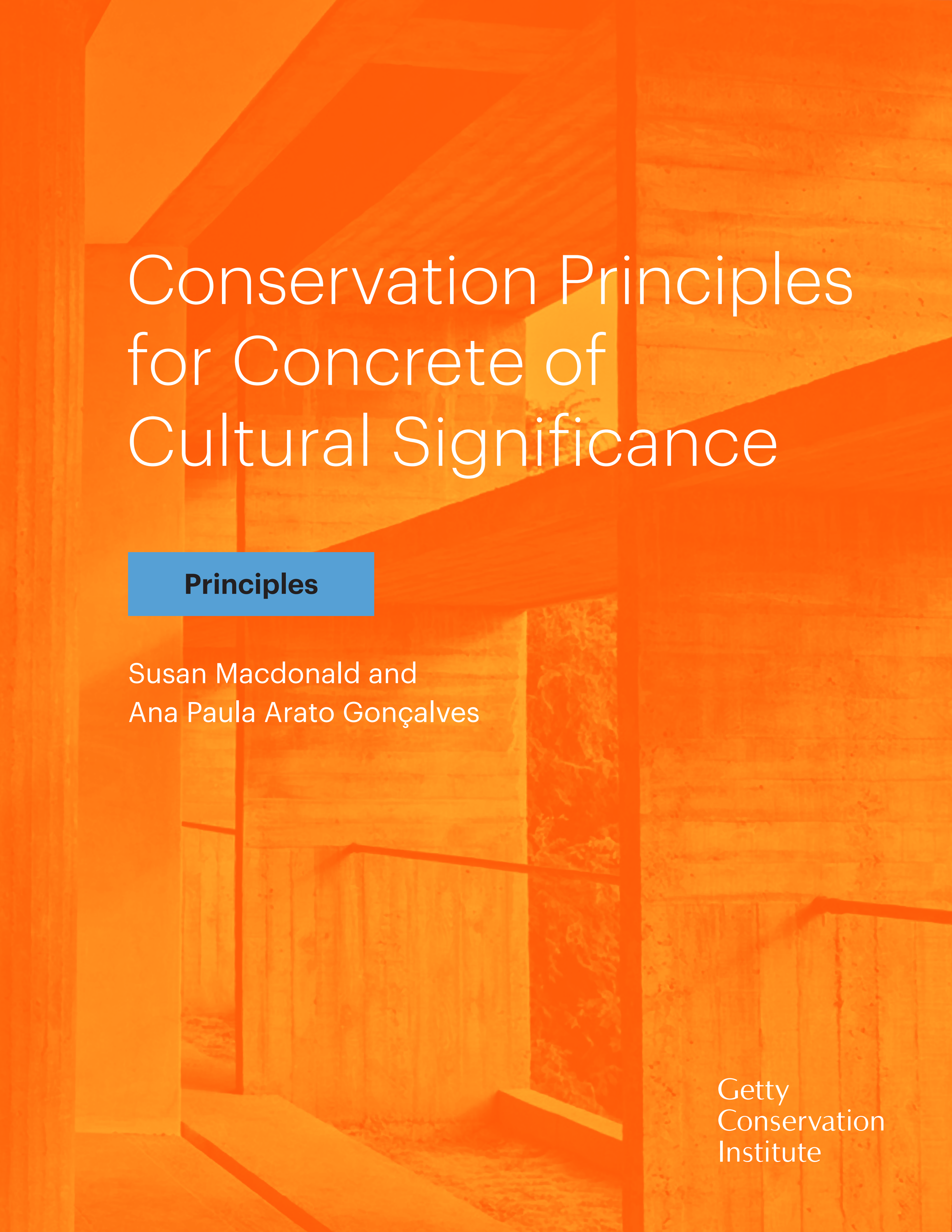

Conservation Principles for Concrete of Cultural Significance

Principles

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Getty
Conservation
Institute

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ISBN: 978-1-937433-80-2 (online resource)
ISBN: 978-1-937433-79-6 (print on demand)

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Introduction

Concrete is arguably the most commonly used building material of the modern era. Initially, its production and construction were largely handcrafted, and its architectural expression was either utilitarian or in imitation of traditional materials such as stone. Subsequent industrialization of cement and concrete production and associated construction techniques through the nineteenth and twentieth centuries brought about the large-scale, fully industrialized construction processes known today. This rapid technological development, especially regarding reinforced concrete, stimulated engineers, architects, and builders to explore and exploit concrete's plastic and structural possibilities in myriad ways to meet the aspirations of the modern world, defining distinct concrete architectural forms and expressions.

In addition, concrete provided an economical solution to the challenges of large-scale construction in the aftermath of World War II, securing its position as the twentieth century's preeminent construction material. Thus, concrete's material, structural, and architectural development over the last two hundred years has produced a remarkably rich and diverse legacy of buildings and structures that are increasingly recognized for their **cultural significance** (see Glossary at the back of this document) (figs. 1a–f).

With this growing recognition comes the need for protection and conservation. Many culturally significant concrete structures will soon or already require conservation; however, the pioneering nature of concrete construction also means that knowledge about its long-term behavior and durability is still evolving. Its conservation poses specific challenges above and beyond those of typical concrete repair projects. These include lack of recognition and appreciation for historic concrete, and the need to balance conservation requirements with standard concrete repair methods.

The approach used to conserve culturally significant concrete shares the same basic methodology with the general repair of concrete. However, historic structures demand additional care to ensure that any work performed retains their cultural significance. Therefore, the impact of any repair work on significance must be carefully assessed. Conservation work may place a higher emphasis on preserving the original material and/or minimizing impacts on the aesthetics of the concrete. For example, in many exposed concrete brutalist buildings where surface finish contributes to significance, repairs may have an adverse impact if they do not blend in suitably with the original surface appearance (figs. 2a, 2b). Other typical areas of concern are loss of original material due to invasiveness of the most reliable concrete evaluation and repair methods; little information on performance of new and emerging repair materials and techniques; and lack of understanding of the long-term effects of adopted repair materials and methods.

Concrete repair is a large and well-established professional activity, constantly fueled by new knowledge, products, and techniques from research, practice, and industry. Concrete conservation, however, is still a relatively new but rapidly emerging field. In most places, architects, engineers, conservators, and contractors have little experience in concrete conservation, with limited specific information available to guide them. As the conservation of concrete draws on knowledge from both the concrete repair and conservation fields, there is a need for basic principles, founded on current best practices from both of these areas, to guide concrete conservation practice and to enhance outcomes for concrete heritage around the world.

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FIGURES 1A–F The evolution of the development of reinforced concrete in the twentieth century has resulted in a variety of extraordinary buildings and structures, each representing new innovations and diverse forms and expressions. Examples include **(a)** Itamaraty Palace, Oscar Niemeyer, Brasília, Brazil, 1970. Photo: Ana Paula Arato Gonçalves, 2013; **(b)** Beira Railway Station, Francisco José de Castro, João Garizo do Carmo, and Paulo de Melo Sampaio, Beira, Mozambique, 1965. Photo: Andrew Moore, 2011, licensed under CC BY-SA 2.0 Generic; **(c)** Tokyo Bunka Kaikan, Kunio Maekawa, Ueno Park, Tokyo, Japan, 1961. Photo: Wei-Te Wong, 2014, licensed under CC BY-SA 2.0 Generic; **(d)** Hollyhock House, Frank Lloyd Wright, Los Angeles, USA, 1921. Photo: Kyle Normandin, 2012, © J. Paul Getty Trust; **(e)** Las Pozas, Edward James, Xilitla, Mexico, 1949–84. Photo: Pavel Kirillov, 2012, licensed under CC BY-SA 2.0 Generic; and **(f)** Penguin Pool, London Zoo, Berthold Lubetkin, London, UK, 1934. Photo: FeinFinch, 2014, licensed under CC BY-SA 3.0 Unported.

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FIGURES 2A, 2B Achieving durable patch repairs that are compatible with the preservation of aesthetic significance of original concrete is a typical challenge in conserving concrete. **(a)** Example of poor aesthetic match. Photo: Ana Paula Arato Gonçalves, 2019, © J. Paul Getty Trust; **(b)** example of good aesthetic match. Photo: Ana Paula Arato Gonçalves, 2019, © J. Paul Getty Trust.

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About This Document

Aim

Conservation Principles for Concrete of Cultural Significance provides a framework for making sound, informed decisions for conserving culturally significant concrete buildings and structures by referencing both concrete repair standards and international conservation principles (see References at the back of this document). Its underlying premise is that concrete, in all its guises, may be of cultural significance and deserves a careful, knowledge-based approach to its care in order to sustain it for future generations.

Not intended as a repair guide, the principles outlined in the pages that follow are meant to provide a logical approach to concrete conservation, leading practitioners through the typical conservation methodology, from investigation to the development of conservation strategies to implementation and maintenance. This document follows the widely accepted step-by-step conservation process summarized in the flowchart in figure 3. It references the methodology used for concrete repair more generally while adding specific considerations that need to be addressed when conserving culturally significant concrete.

The purpose of this framework is to develop a consistent approach to achieve optimal outcomes for culturally significant concrete and improve standards of conservation. It also provides basic terminology (defined in the Glossary) that can be shared by the various disciplines involved in concrete conservation.

Scope

The principles in this document are relevant for reinforced and unreinforced concrete dating from the nineteenth century onward identified as being of cultural significance. It covers all forms of concrete heritage: buildings of varied uses and typologies, and structures such as bridges, fortifications, landscape features, artworks, and decorative elements. It includes cast-in-place (in situ) and precast concrete and the range of reinforced systems that have been used over time, including prestressed and pre- or post-tensioned reinforcement. Concrete has been finished in a variety of ways; it has historically been rendered, painted, exposed, board-marked, bush-hammered, stamped, acid-washed, mosaicked, and tiled (figs. 4a–e). These finishes may contribute to significance and can be vulnerable during repair projects.

Concrete can play a structural or nonstructural role, but the principles for conservation are the same, although the type and extent of assessment and subsequent conservation measures may be different. The specialist professionals involved in the conservation process may also vary according to whether the concrete carries load or not.

THE CONSERVATION PROCESS

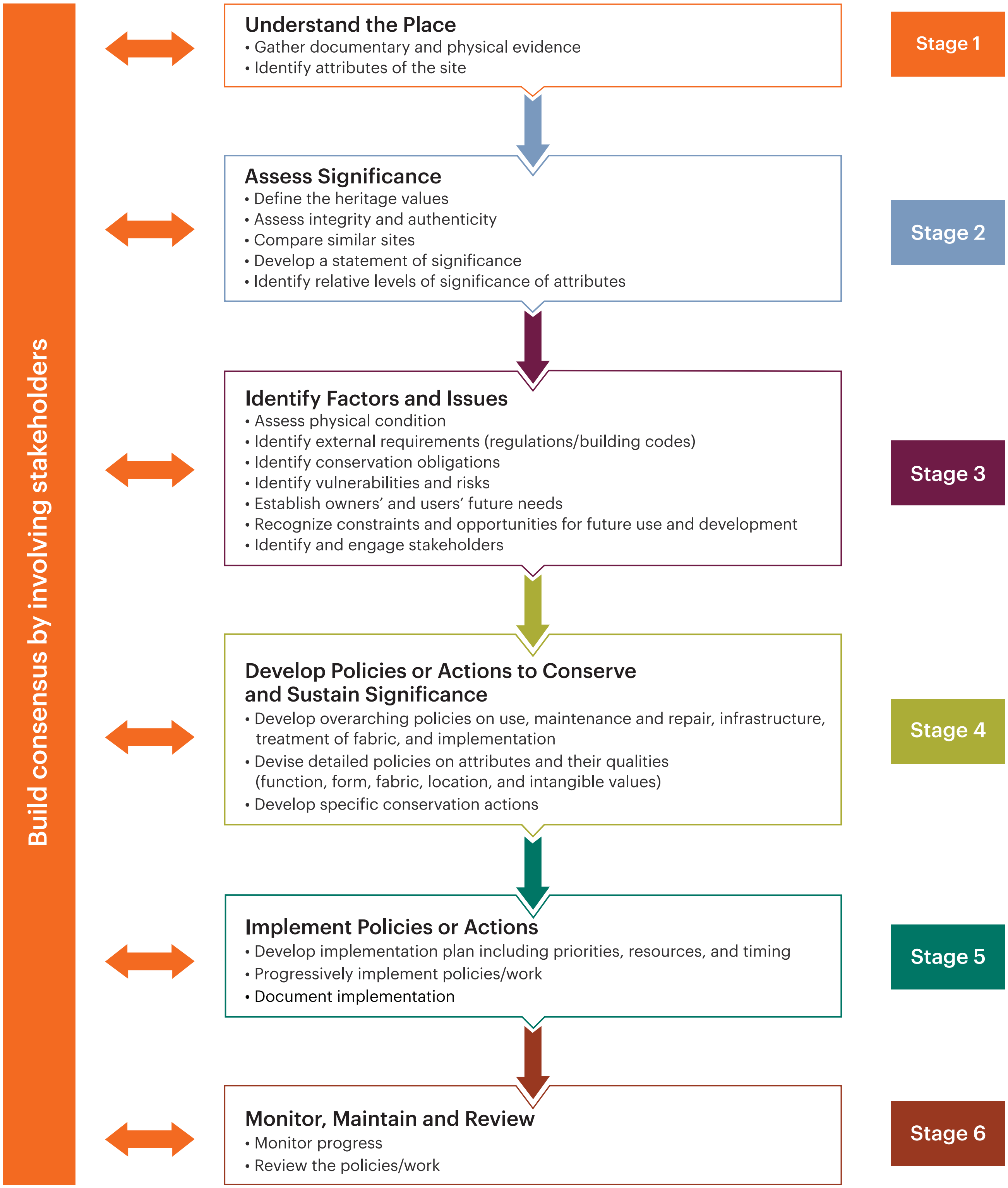

FIGURE 3 Flowchart describing the typical step-by-step process in the conservation of a heritage site. Based on The Burra Charter Process (Australia ICOMOS 2013).

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FIGURES 4A–E Examples of concrete finishes: **(a)** tile cladding on concrete, Sydney Opera House, Jørn Utzon, Sydney, Australia, 1973. Photo: Greg O'Beirne, 2006, licensed under CC BY-SA 3.0 Unported; **(b)** bush-hammered concrete, Barbican Centre, Chamberlin, Powell & Bon, London, UK, 1976. Photo: Ana Paula Arato Gonçalves, 2019, © J. Paul Getty Trust; **(c)** ribbed concrete with exposed aggregate. Photo: Ana Paula Arato Gonçalves, 2019, © J. Paul Getty Trust; **(d)** board-marked concrete. Photo: Ana Paula Arato Gonçalves, 2019, © J. Paul Getty Trust; and **(e)** concrete mimicking stone, Palais d'Iéna, Auguste Perret, Paris, France, 1937–46. Photo: Ana Paula Arato Gonçalves, 2018, © J. Paul Getty Trust.

Limitations

All conservation projects are subject to a range of considerations and are developed in accordance with available resources, time, and access. The context in which conservation projects operate varies from country to country. Project management, contracting arrangements, and the roles and availability of the cited professionals may thus be different. Nevertheless, these principles outline optimal practice, with the acknowledgment that local circumstances will affect how they may be applied.

Terminology

The terminology used in this document is defined in the Glossary. Conservation-specific terms are drawn from international conservation practice, while other technical terms are defined according to standards of the concrete repair industry and are adapted to a conservation context when needed.

This document defines *concrete* as a composite material of aggregates of various sizes and shapes, broadly categorized as fine (commonly sand) and coarse (typically gravel and stone), combined with cement paste (cement and water), which acts as a binder. It may or may not contain admixtures and other cementitious materials such as fly ash, slag cement, and silica fume. Reinforced concrete contains bars, wires, or other elements (typically steel, earlier iron, and, more recently, glass or polymer fibers) that enhance the tensile strength of the material.

Conservation here is an umbrella term covering all the processes that might be used to retain what is important about a heritage site (its cultural significance). These processes include preventive measures, repair, restoration, maintenance, and, in some instances, reconstruction.

Concrete heritage encompasses all forms of concrete that are of cultural significance, and the terms *building* and *structure* are used to embrace all typologies of this concrete heritage.

THE CONCRETE CONSERVATION PROCESS

START HERE

1. PROJECT PLANNING

1. Identify a suitably skilled team
2. Define project goals
3. Identify stakeholders
4. Identify regulatory requirements

Is there a statement of significance?

3. DEVELOP CONSERVATION STRATEGIES

3.1. CONSERVATION CRITERIA

1. Develop conservation criteria
2. Consider different conservation approaches
3. Assess impact of proposed strategy on significance
4. Select appropriate materials and methods

3.2. UNDERTAKE TRIALS, MOCK-UPS, AND TESTING

1. Undertake trials/mock-ups off the structure
2. Test and evaluate trials/mock-ups

Does it satisfy conservation criteria? yes / no

3. Undertake trials/mock-ups on the structure
4. Test and evaluate trials/mock-ups
5. Develop final construction drawings and specifications

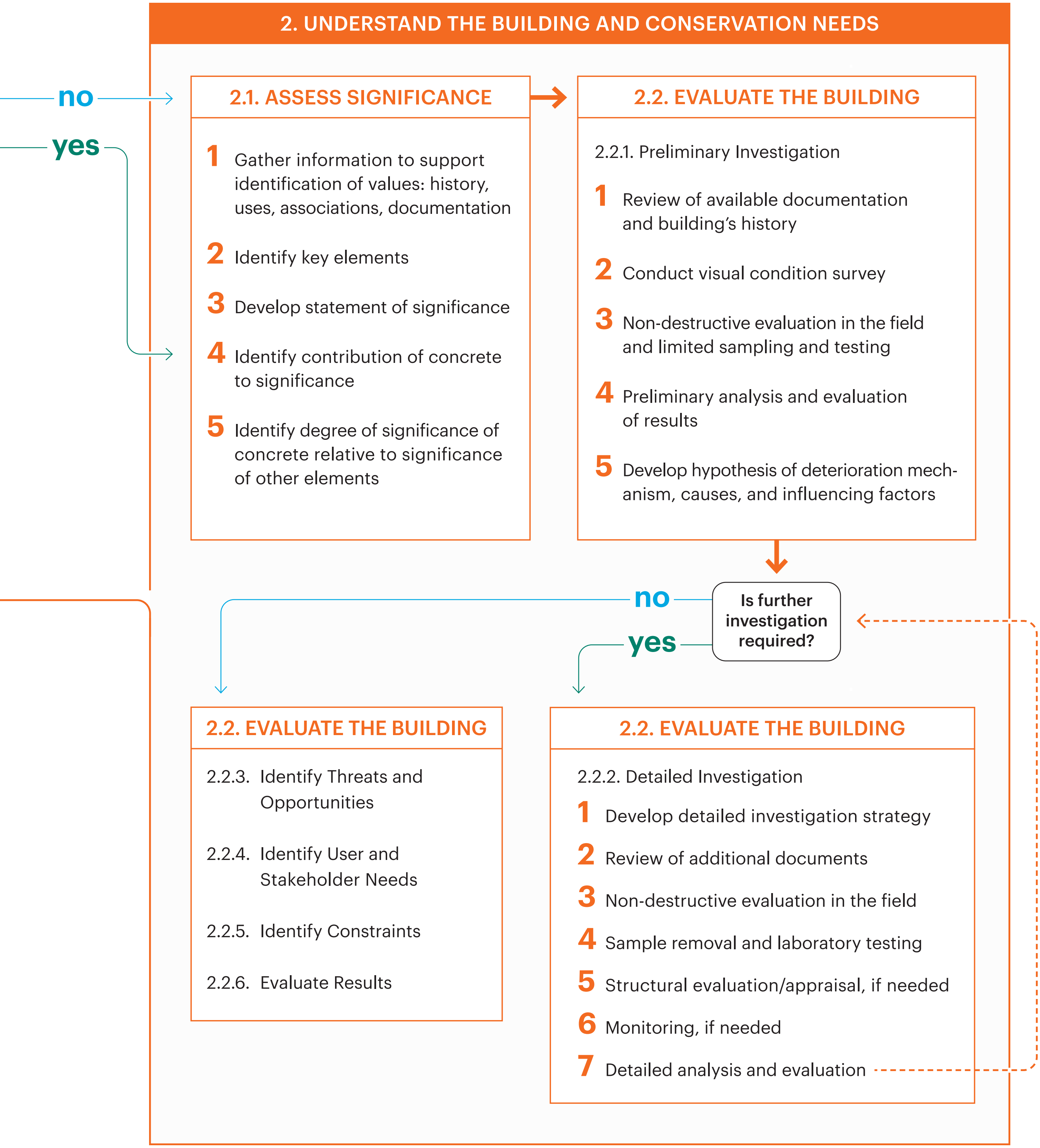
4. IMPLEMENTATION

1. Select contractors prioritizing necessary skill level
2. Undertake on-site training for contractors
3. Implement conservation work
4. Quality control
5. Documentation of work process and result

5. MAINTENANCE AND MONITORING

1. Develop maintenance plan
2. Monitor threats, opportunities, treatments, and repairs

FIGURE 5 Flowchart illustrating the entire concrete conservation process, combining best practices in concrete repair and conservation processes (see fig. 3).



Principles The principles presented in this document are summarized in the flowchart in figure 5. It illustrates the entire concrete conservation process, combining best practices in concrete repair and conservation processes.

1. PROJECT PLANNING

The project planning phase provides the foundation for a successful project. This section emphasizes the most crucial areas for concrete conservation, recognizing that other areas, such as budget and schedule, are similar to regular project planning.

1.1. Identify a Suitably Skilled Project Team

Concrete conservation is a specialized multidisciplinary activity. It demands that practitioners who have appropriate technical knowledge and experience in concrete conservation are engaged in all the project's phases—assessment, testing, evaluation, development of conservation strategies, implementation, and maintenance—to ensure that the work is technically effective and sustainable, and meets the specific conservation needs of the building.

Today, many projects prioritize cost in selecting professional and contracting teams; success, however, depends on the knowledge, skills, and experience of the team. Therefore, the selection process should prioritize qualifications and experience over the lowest bid. It is difficult to achieve all technical and conservation requirements of heritage projects with a team of limited experience. In the case of concrete repair, low-quality work will inevitably lead to rework and, therefore, unnecessary loss of original material and additional cost.

The main specialized fields that can play a role in concrete conservation are listed below.

- Engineers or architects with knowledge, skills, and experience in concrete conservation should be engaged to lead condition assessment work, evaluation, and development of conservation strategies, and to oversee implementation.
- Structural assessment/appraisal of concrete, development of structural repair strategies, and implementation should be undertaken by suitably qualified engineers and contractors. Given that concrete is often used as a structural material, projects that move beyond surface repairs require this expertise.
- Conservators with knowledge, skills, and experience in concrete conservation can provide a useful link between architects/engineers and craftspersons. Their contribution is particularly valuable where the appearance of the repair is of importance, requiring tailoring of repair materials and techniques to the specificities of the site.

- Sampling and laboratory testing and analysis should be undertaken by suitably experienced laboratories and guided by international and national standards, tempered to conservation needs. The professionals responsible for testing the concrete should be involved in developing the testing and sampling strategies.
- Manufacturers of repair or treatment products should not be used in lieu of independent consultants to undertake assessment work and develop repair strategies. Manufacturers can, however, play a role in developing site-specific repair materials by working closely with the independent consultants.
- Contractors with specialized knowledge, skills, and experience in working with significant concrete structures are essential to the execution of durable and appropriate repairs and treatments. Those with experience in conserving concrete can be difficult to find in many parts of the world. An acceptable alternative is to employ contractors highly experienced in high-quality concrete repair who can demonstrate a careful and thoughtful craftsperson-like approach, who are willing to undergo on-site training, and who embed the detailed quality control necessary during execution.

Throughout the project, a collaborative approach is essential and should be fostered between the various parties involved in the assessment, development of conservation strategies, trials, mock-ups, implementation, maintenance and monitoring phases. Adequate time and budget for each phase needs to be allocated.

Retaining the same team throughout the process, from evaluation to implementation, has the advantage of building knowledge over the various stages of the project. In cases where this is not possible, the need to secure a suitably qualified and skilled team remains essential in all steps of the conservation process.

1.2. Identify Project Goals

A clear understanding of the goals of the concrete conservation work should be established and used to guide the project from its inception. These objectives should be refined and agreed early on with the project team and stakeholders. The project should aim for best conservation practice, balanced with owner and user needs, available resources, and other factors such as sustainability, accessibility of the area to be conserved, expectations of the service life of the building and of the repairs, protection systems, and future maintenance commitments.

1.3. Identify Stakeholders

It is necessary to identify the stakeholders who may influence outcomes of the project and what their roles will be.

1.4. Identify Regulatory Requirements

Buildings and structures that are statutorily protected may require approval from the relevant heritage or planning authority for any sampling, testing, exploratory opening, or other works occurring during the assessment stage, as well as for implementation, in addition to the usual regulatory requirements for typical construction projects. Beyond heritage regulatory requirements, it is important to identify relevant building codes, safety and accessibility standards.

2. UNDERSTAND THE BUILDING AND CONSERVATION NEEDS

The effectiveness of the conservation outcome is directly dependent on the information used to guide decision-making. Similar to typical conservation, the process described below gathers knowledge about the cultural significance of the concrete, its physical characteristics and conditions. The technical investigation activities involved should be guided by best practices and standards in the concrete repair field balanced with the specific needs of conservation.

2.1. Assess the Cultural Significance of the Building and the Significance of the Concrete

Common to all conservation projects is the need to understand the cultural significance of the building or structure, the elements (character-defining features) that contribute to that significance, and the relative levels of significance of these elements. Understanding significance is essential to developing appropriate conservation strategies that balance technical and conservation requirements and to evaluating the impact of any proposed work on the significance of the building.

Concrete may contribute to the cultural significance of a building under a number of the typical criteria used in heritage assessment. For example, it may carry historic significance for demonstrating evidence of an important aspect of construction development or a historical event, scientific significance for demonstrating feats of technological advancement, aesthetic significance as a great work of architecture, or other values used to define cultural significance (figs. 6a–c). The assessment of significance should also identify the level of the concrete's contribution relative to other elements, as well as which specific characteristics of the concrete contribute to the significance of that heritage.

Understanding the historic context of the building or structure plays an important role in assessing its significance. It may also give clues to composition, characteristics of the concrete, and the way the material was made. This is important to the technical evaluation work that follows, as concrete technology evolved considerably through the nineteenth and twentieth centuries.

The typical steps in the significance assessment process are as follows:

1. Gather archival evidence.
2. Gather physical evidence through documentation, survey, and visual inspection.
3. Identify the key elements (character-defining features) of the building that demonstrate significance.
4. Develop a statement of significance.
5. Identify the contribution of the concrete to the cultural significance of the building or structure. Is the concrete a character-defining feature? For example, does it have historic, scientific, or aesthetic significance?

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FIGURES 6A–C Concrete buildings convey many of the values typically used to define heritage significance, for example: **(a)** concrete fence posts with barbed wire, Auschwitz, Oświęcim, Poland, 1940–42, carry historic and remembrance values. Photo: Pimke, 2006, courtesy Wikimedia Commons, CC BY-SA 3.0 Unported; **(b)** Villa Hennebique, François Hennebique, Bourg-la-Reine, France, 1903, conveys scientific value. Photo: Eurobas, 2009, courtesy Wikimedia Commons, CC BY-SA 3.0 Unported; and **(c)** Salk Institute for Biological Studies, Louis I. Kahn, La Jolla, California, 1965, has aesthetic value. Photo: Gail Ostergren, 2011, © J. Paul Getty Trust.

2.2. Evaluate the Building: Investigate Physical Conditions and Identify Threats/Opportunities, User and Stakeholder Needs, and Constraints

Developing an effective conservation strategy relies on a thorough evaluation of the building. Many contributing factors affect the technical performance of a concrete structure, including workmanship, design, selection of materials, environmental factors, use, and lack of maintenance. Thus, it is important to understand the material characteristics of the structure and identify current or future threats in order to increase the effectiveness of conservation strategies. Equally important is determining external factors that will influence the conservation strategy. The needs of the user, owner, and other relevant stakeholders must also be identified. The goal is to pinpoint all the requirements to develop an acceptable and sustainable conservation strategy that meets technical, conservation, and user criteria.

It is crucial to follow a well-established investigation methodology for concrete (see American Concrete Institute 2018, 2019; European Committee for Standardization 2004–17, part 9). With additional care, these methodologies are equally applicable to culturally significant concrete buildings.

2.2.1. Preliminary Investigation

The preliminary investigation work should begin by reviewing the available documentation and the building's history, including past uses, renovations, and maintenance records.

Next, the team should characterize the environment and its aggressiveness to concrete. Consider the local climate; exposure to sun, freeze-thaw cycles, wind, and rain for each concrete element; pollution levels, especially CO_2 and sulfates; and exposure to chlorides such as deicing salts or proximity to the ocean; and other contaminants that might lead to deterioration of concrete.

A visual condition survey should be conducted to document and identify current conditions and the extent and degree of deterioration.

In some instances, easily available nondestructive field evaluation can be used at this stage to identify key material characteristics and to locate important subsurface conditions such as areas of delamination using sounding techniques. Detached or loose material found on-site should be collected for examination and could potentially be used for preliminary testing.

Analysis of the preliminary investigation results should be followed by development of a hypothesis that correlates identified deterioration with potential causes and influencing factors.

The need for detailed investigation should then be evaluated.

2.2.2. Detailed Investigation

When needed, a detailed investigation strategy should be proposed that balances conservation and technical needs, taking into consideration the hypothesis developed and available resources. Preference should be given to nondestructive, in situ diagnostic techniques. Destructive investigation techniques should be used to confirm findings of nondestructive techniques and to gather additional essential information that cannot be obtained with nondestructive techniques.

Establishment of monitoring to identify or confirm active deterioration should be considered, as it can be an effective way to determine deterioration rate and level of intervention required in accordance with the conservation principles of minimal intervention. Monitoring can thus play an important role in investigation and may be a conservation strategy in its own right, one used to identify a critical point in the deterioration process when conservation action is needed, or to control a risk factor.

The proposed detailed investigation strategy should be guided by knowledge about the significance of the structure, how it was built, and appropriateness for obtaining the best possible investigation results.

Sampling for laboratory testing provides best results when the sampling strategy is developed in collaboration with the professional who will analyze the samples. The goal of the sampling strategy should be to ensure reliable and useful results while minimizing the damage and loss of original material as much as possible.

Locations for destructive investigation, such as exploratory openings and sampling, should be representative of materials and conditions, and should be inconspicuous whenever possible.

For load-bearing concrete, if the use/loading is likely to change or if there are signs that the load-bearing structure is not performing adequately, conduct a structural evaluation/appraisal to determine the building's structural capacity, residual service life, and fitness for continued or proposed use. As part of the structural evaluation/appraisal, determine the degree of intervention needed for the structure to meet performance requirements.

The analysis of investigation results may confirm the deterioration mechanisms threatening both performance and significance of the concrete, and identify the need for repair or treatment. This process could also reveal the need for further testing.

2.2.3. Identify Threats and Opportunities

The team should identify threats and opportunities that could affect the significance of the concrete in the future. Examples of threats include factors that might trigger or aggravate deterioration, and examples of opportunities include characteristics that might be explored to promote conservation, such as an overdesigned structure that can safely carry more than the current load. The potential impact of these threats and opportunities on cultural significance should also be assessed to help prioritize actions for mitigating or exploring them.

2.2.4. Identify User and Stakeholder Needs

It is important to investigate possible impact of complying with stakeholder needs on cultural significance of the building. This may reveal requirements that will need to be negotiated to minimize impact. For example, any changes in use for the building should not incur structural changes that negatively impact significance.

User and stakeholder needs may lead to further investigation if, for example, loads are going to be added to the structure.

2.2.5. Identify Constraints

The development of a conservation strategy also needs to consider nontechnical constraints such as availability of resources, technology, and experienced workers; accessibility to the site; and the need to comply with local standards and policies, such as environmental restrictions on the use of certain chemicals, and with regulatory agencies that are involved in any part of the work.

2.2.6. Evaluation of Results

Next, evaluate holistically how all these factors affect the significance of the building and of the concrete; prioritize needs by considering the urgency of necessary action and scale of impact on significance; and evaluate how the identified factors constrain the choices of appropriate and feasible conservation strategies. This process benefits greatly from the collaboration of multidisciplinary professionals involved in the project, as indicated previously.

The evaluation findings should be compiled in a report that can be used as a basis to develop a conservation strategy that aims to balance user/stakeholders, technical, and conservation requirements.

3. DEVELOP CONSERVATION STRATEGIES

Concrete conservation strategies should be developed by balancing best practices for concrete **repair**, **treatment**, and **maintenance** (see Glossary) with conservation needs. However, in some instances, there may be conflicts. Therefore, decisions should be made on the basis of a clear understanding of the compromises involved and their long-term consequences.

Established processes and techniques have been codified in guidelines and standards for repairing and treating concrete such as those provided in the *Concrete Repair Manual* (American Concrete Institute and International Concrete Repair Institute 2013), ACI 562-16 (American Concrete Institute 2018), and European standard EN 1504 (European Committee for Standardization 2014–17). Other countries have their own standards, which should guide the development and implementation of conservation strategies for concrete structures along with typical conservation criteria.

Options involving different degrees of intervention need to be considered:

a) Do nothing for a certain time but monitor;
b) re-analyze the structural capacity, possibly leading to downgrading in function;
c) prevent or reduce further deterioration;
d) strengthen or repair and protect all or part of the concrete structure;
e) reconstruct or replace all or part of the concrete structure;
f) demolish all or part of the concrete structure. (European Committee for Standardization 2004–17, part 9, p. 9)

The decision-making process should compare the benefits and potential risks to the significance of the building for each option above, and select the one that provides the best balance of the conservation criteria presented on page 21.

Preventive treatments that can arrest or slow deterioration may minimize or delay more invasive repair. For concrete, this may mean applying penetrating or film-forming materials to the surface, or using electrochemical methods such as cathodic protection. As with repair options, the advantages and disadvantages of each treatment need to be carefully assessed according to the criteria listed on page 21.

3.1. Conservation Criteria

A successful concrete conservation strategy should always have the ultimate goal of maximizing conservation of the significance of the building. The strategy must be tailored to the specific requirements of each project and adhere to the following criteria, which encompass both technical and conservation requirements:

- Address causes of deterioration by minimizing or eliminating the factors contributing to them.
- Consider severity and urgency of any identified deterioration.
- Meet technical requirements for durable repair or treatment (expectations for the service life of the structure and durability of repairs or treatments).
- Meet user and stakeholder needs without compromising significance.
- Minimize additional loading requirements that may have structural implications impacting significance.
- Consider feasibility of implementing the strategy, such as availability of resources, skilled workers, local constraints on certain chemical treatments, etc.
- Consider maintenance needs of any repair or preventive treatments selected, and ensure enough resources are in place.
- Consider sustainability of the proposed materials and techniques, in terms of both long-term effectiveness and environmental impact.
- Minimize the risk of negative impact of any proposed work on the significance of the concrete by doing the following:
    - Exercise a cautious approach. Do as little as possible and only as much as necessary, taking into consideration the long-term effects on technical performance.
    - Select compatible repair materials and methods guided by investigation, testing, and analysis of results to ensure durable repairs that preserve the concrete's significance.
    - Where the surface finish of the concrete contributes to significance, repairs should aesthetically match the original finish as closely as possible. The selection criteria for the repair materials should balance factors such as performance and aesthetic compatibility (texture, color, and profile).
    - Repairs or preventive treatments should not preclude future investigation, repair, or reapplication of such treatments.
    - Avoid use of experimental, untested, or poorly reviewed techniques and materials. Where few options are available and a new technique may have the potential to meet conservation needs, field and laboratory trials and monitoring should be undertaken for a period suitable for determining the long-term effect of the technique prior to application on the significant concrete.
    - Reversibility should be a goal whenever new materials or elements need to be added, but only as far as it is feasible and does not compromise the quality of the solution.

3.2. Undertake Trials, Mock-ups, and Testing of Repair and Treatment Materials

In conservation, the iterative process of conducting trials, creating mock-ups, and testing repair and treatment materials is crucial. This provides an opportunity to refine the repair and treatment techniques and materials to ensure their compatibility and effectiveness in conservation and performance terms before application on the building or structure. The process should inform the development of construction documents.

Trials and mock-ups should mimic as closely as possible the conditions expected for site work in order to help determine if the proposed repair or treatment meets all requirements defined for the project; for example, if the repair aesthetically matches the original concrete and if the project is cost effective and feasible with the resources available. When time allows, trials can also reveal if the repairs will weather appropriately.

Appropriate contractors or conservators with proven experience should carry out the trials and mock-ups so they can help develop and refine the conservation techniques. This same level of skill should be available in the implementation phase. Initially, trials and mock-ups should be undertaken independent of the building before in situ mock-ups are attempted.

Laboratory and field-based testing of repair and treatment materials are typically part of the process and should be programmed into the mock-up phase. Testing may include materials testing, verifying effectiveness of preventive treatments, and bonding of patch repair.

Once the most likely appropriate techniques and material have been identified, in situ mock-ups can assist in refining these techniques and developing protocols and reference repairs, which can be used to inform the tender/bid process and implementation phases of the project. Mock-ups should be undertaken in discreet locations on the building that are also representative of typical conditions. In some cases, in situ trials and mock-ups may require regulatory consent.

Each step of this phase of work may include as many iterations as necessary to meet the requirements defined for the conservation project.

4. IMPLEMENTATION

Concrete conservation work involving repair and application of treatments should be undertaken according to technical standards such as ACI 562-16 and EN 1504, and guidelines such as those indicated in the ACI *Concrete Repair Manual*, with additional considerations to accommodate conservation needs.

On-site training for contractors should be provided that defines expectations and standards for the conservation work. This will ensure there is a shared understanding of the standard and level of craftsmanship required.

Quality control in all phases of implementation is essential. The team should establish and implement a quality control process during the work, including a clear definition of roles and responsibilities for undertaking and overseeing the standards of work. It is also necessary to provide protocols and standards for different repair and treatment methods, undertake regular inspections, and check new work against the agreed standards and mock-ups.

The conservation work should be documented and a record of the work provided to the owner, including conservation strategy, record of materials used, mapping of all patches and areas treated, and protocols describing methods for different repair and treatment types. This is important for future assessment and work to the structure.

5. MAINTENANCE AND MONITORING

As with any built heritage, periodic maintenance and monitoring of conditions and risk factors affecting the concrete are essential for prolonging the effectiveness of the conservation work and sustaining the building. Maintenance and monitoring can also be considered conservation actions and may minimize the need for large-scale interventions that incur the loss of original material.

Actions to safeguard the original concrete and any repairs/treatments applied should be integrated into the building's general maintenance plan. Successfully implementing a maintenance plan requires a dedicated budget, appropriate access to the concrete, and appropriately skilled maintenance personnel with clearly identified roles and responsibilities.

The maintenance plan should include the following:

- Protocols and standards for any periodic maintenance activities, such as cleaning and minor repairs, specifying materials, methods, and also identifying the skills required for undertaking the work.
- A preapproved list of specialists such as consultants and contractors who have the requisite knowledge, skills, and experience for ongoing care of the place.
- A mechanism for recording maintenance activities.

Monitoring should include the following:

- Periodic inspection of treated/repaired areas and their surroundings for reoccurrence of deterioration, for issues in the interaction between repair material and substrate, and to determine if the expectations of service life of the repairs and treatments are being met.
- Measuring risk factors against thresholds to trigger mitigation actions.

Acknowledgments

We are grateful for the constructive comments from our peer reviewers:

Michael Balletta and John Drewett, CRL Restoration

Myriam Bouichou and Elisabeth Marie-Victoire, Laboratoire de Recherche des Monuments Historiques

Véronique Bouteiller, French Institute of Science and Technology for Transport, Development and Networks

Kelly Ciociola, Rosa Lowinger, and Christina Varvi, RLA Conservation

Gina Crevello, Echem Consultants

Catherine Croft, Twentieth Century Society

David Farrell, Rowan Technologies

John Fidler, John Fidler Preservation Technology

Paul Gaudette and Ann Harrer, Wiss, Janney, Elstner Associates

Carsten Hermann, Historic Environment Scotland

Wessel de Jonge, WDJ Architects

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Arun Menon, Structural Engineering Laboratory, Department of Civil Engineering, Indian Institute of Technology, Madras

Gabriel Pardo Redondo, Heritage and Architecture, Faculty of Architecture and the Built Environment, Delft University of Technology (TU Delft)

Stuart Tappin, Stand Consulting Engineers

John Walsh, Highbridge Materials Consulting

Simeon Wilkie, Getty Conservation Institute

We would especially like to acknowledge the following institutions for gathering comments from their members:

Docomomo – International Specialist Committee on Technology (Docomomo ISC/T)

International Council on Monuments and Sites – Twentieth Century Heritage International Scientific Committee (ICOMOS ISC20C)

Glossary

Cement. Any of a number of materials that are capable of binding aggregate particles together. Portland cement is a hydraulic cement produced by pulverizing a material resulting from calcining a mixture of clay and limestone or similar materials.

Concrete. A composite material of aggregates of various sizes, broadly categorized as fine (commonly sand) and coarse (typically gravel and stone), combined with cement paste (typically cement and water), which acts as a binder. It may or may not contain admixtures and other cementitious materials such as fly ash, slag cement, and silica fume. See also *Reinforced concrete*.

Concrete heritage. Used to describe a building, structure, or other typology made of concrete and deemed to be of cultural significance.

Conservation. An umbrella term to mean all the processes of looking after a place so as to retain what is important about it or its cultural significance. These actions include repair, restoration, maintenance, and, in some instances, reconstruction (Australia ICOMOS 2013).

Contractor. A "person or entity that is under contract to the owner for the implementation of repairs to the structure." (International Concrete Repair Institute 2015)

Craftsperson approach. Characterizes work that is executed with a high level of skill and experience.

Cultural significance. The combination of cultural values of a place (such as aesthetic, historic, scientific, social, or spiritual values) to past, present, or future generations.

Deterioration. The "physical manifestation of failure of a material (e.g., cracking, delamination, flaking, pitting, scaling, spalling, staining) caused by service conditions or internal autogenous influences." (International Concrete Repair Institute 2015)

Evaluation. The process of assessing a building's needs to define the appropriate conservation strategy, which may include preventive measures, repair, restoration, and maintenance of concrete. Evaluation involves determining the current condition of the concrete, identifying the cause and extent of deterioration, and identifying any factors that could affect the concrete in the future. This process may include field and laboratory testing and engineering calculations.

Maintenance. The continuous and regular protective care and upkeep of a building or structure.

Reinforced concrete. Concrete with embedded reinforcement, usually steel bars, wire, or mesh, to provide added tensile strength.

Repair. To restore to a sound condition after damage or deterioration. May involve restoration, such as returning dislodged parts to their original location, and/or reconstruction, where deteriorated or lost material is replaced with new material.

Restoration. The act of reestablishing a building or structure to an earlier form and/or appearance.

Sampling. The selective removal of material in order to undertake laboratory analysis and testing.

Structural evaluation or appraisal. "The process of determining, and judging the structural adequacy of a structure, member, or system for its current intended use or performance objective" (American Concrete Institute 2018, 20)

Testing. Procedures that use equipment to assist in understanding the material or physical properties of the concrete structure. Nondestructive testing and analysis refers to methods that do not physically impact the concrete.

Treatment. "The application of a chemical or process with the aim of affecting a desired change." (International Concrete Repair Institute 2015)

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Getty Conservation Institute

Conservation Principles for Concrete of Cultural Significance was developed as part of the Concrete Conservation Project of the Getty Conservation Institute's Conserving Modern Architecture Initiative (CMAI). The Concrete Conservation Project has the long-term goal of improving the conservation of culturally significant concrete buildings and structures. For more information on CMAI visit www.getty/conservation/our_projects/field_projects/cmai

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