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Strategies for the Conservation of Historic Concrete Structures

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Welcome and introduction:

Dr. Barbara Lubelli; TU Delft
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Summary and conclusion:

Dr. Barbara Lubelli, Delf

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Abstracts of the individual contributions available here
Abstracts der Einzelbeiträge hier abrufbar: http://s.fhg.de/wtaconcrete22

Overview of the project CONSECH20

Conservation of 20th century concrete cultural heritage in urban changing environments

Cristiana Nunes, Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences

Keywords: historic concrete, social interest, heritage values, maintenance, reuse

CONSECH20 is a European research project supported by the JPI CH Heritage in Changing environments programme developed from 2019 to mid-2022. The project aimed to develop approaches for the conservation and protection of the 20th century heritage concrete buildings against the ever-changing urban impacts, considering both technical and social aspects.

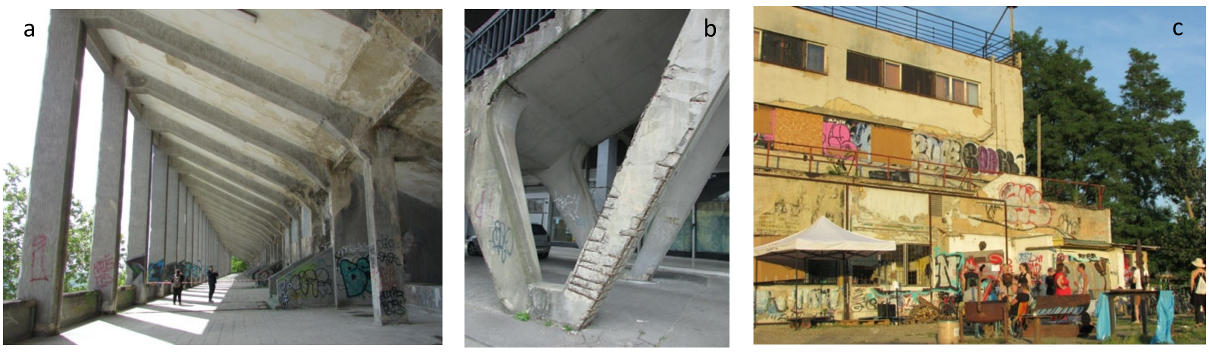
In general, the rehabilitation of urban spaces, which are rich in heritage values, has been almost always focused on the building to be preserved, relegating to a secondary level the social functions and dimensions of support to the local communities. Defending the tangible heritage values while forgetting their necessary relation with the social dimension and the intangible sense of heritage has contributed to the abandonment and consequent degradation of buildings.

The CONSECH20 project aimed to support better maintenance practices by promoting public awareness and interest in this recent heritage. It focused on historic reinforced concrete constructions built mostly until 1960. Focus was given to buildings with social interest, in the sense of bringing people together, to strengthen the link between society and the 20th century architectural heritage.

The project used case studies of concrete buildings in four of the participating countries: Cyprus, Czech Republic, Italy, and The Netherlands. The assessment of the case studies encompassed the analysis of the construction history, usage history, state of conservation, and heritage values. Both constructions that need conservation or are abandoned and those that have undergone interventions and are functional were selected to assess the trends in maintenance, repair, and reuse (see figure below). The methodology used is reflected in the project's online interactive open-access database that the public can use to document more concrete heritage buildings.

Each consortium partner has developed digital storytelling videos about concrete cultural heritage in each country for engaging communities in promoting heritage and fostering partnerships with cultural heritage institutions. The public is encouraged to make their own videos and upload them to the online database.

Conservation proposals for selected buildings needing repair were made based on the in-depth analysis of their history and materials. The proposals are also available on the project database and website and can be implemented by the authorities responsible for the buildings.



Examples of case studies in the Czech Republic: a) Abandoned structure: view of the Strahov stadium in Prague during an opening day for visitors; b) Detail of the Strahov stadium showing corrosion of the reinforcement due to inadequate concrete cover and lack of maintenance; c) Building in need of conservation: view of the Fuchs restaurant in Prague during a local community party.

Innovative materials and techniques for the conservation of the 20th century concrete-based cultural heritage

María J. Mosquera, Universidad de Cádiz

Keywords: concrete, surface treatment, Innovaconcrete

Nowadays, the application of surface treatments, which prevent the water ingress and fill the cracks produced by degradation, is the preferred choice for preserving historic concrete. Although coatings such as epoxy and acrylic resins are commonly employed with this aim, they present significant drawbacks associated to thick layer formation on concrete. These layers can modify the aesthetic conditions of the surface and, especially, they present low durability due to low penetration and poor adhesion to the substrate. Impregnation treatments, on the other hand, present a low viscosity, and consequently have the ability to penetrate deeper and react in situ within the pore structure of the damaged substrate, promoting long-lasting effectiveness. Specifically, silica oligomer/monomer-based sols (e.g.¸ tetraethoxysilane, TEOS) are widely used in the stone conservation market due to their advantages and their economical cost comparable to other alternatives. Their low viscosity allows them to penetrate deeply into the porous structure and after polymerization, which occurs upon reaction with environmental moisture, a stable gel with a silicon-oxygen backbone is formed. The application of silica oligomer/monomer-based products as an impregnation treatment on concrete has been hardly investigated, despite recent studies indicating their higher effectiveness in comparison to other impregnation products (such as sodium silicate and nanosilica). However, the high pH and different composition of the cement matrix compared to stone is likely to modify the interaction of these products with concrete and thus, it requires to be investigated.

Our research group has developed, in the framework of the European project InnovaConcrete, a completely innovative impregnation treatment to produce calcium silicate hydrate (C-S-H) gel—responsible for the engineering properties of cement paste—inside the cracks/pores of decayed concrete monuments. New C-S-H gel is produced into the concrete porous system as consequence of reaction between silanol groups from silica-based products and Ca^{2+} ions from portlandite, one of the main resultant products of cement hydration. Complementarily, multifunctional treatments combining C-S-H production with additional performances (superhydrophobicity or self-cleaning ability) have been developed. The optimization of the proposed solutions has been assisted by the use of theoretical tools (multiscale modelling approaches) together with experimental tools (laboratory and in situ validation). All the InnovaConcrete solutions were subjected to experimental validation at laboratory scale in a total of 680 mortar specimens. The mortars were subjected to physical degradation, chemical degradation and mechanical degradation. In addition, validation of the InnovaConcrete materials has been carried out on 618 representative mock-up samples, with similar composition and structural properties to the selected case studies. Finally, the InnovaConcrete solutions have been evaluated on seven case studies. All of them showed a suitable performance and durability, being one of the monuments (angle sculpture) in Italy completely restored by using the solutions developed in InnovaConcrete.

Textile reinforced concrete – Opportunities for the restoration of historical concrete structures

Jeanette Orlowsky, Technische Universität Dortmund, Dortmund, Germany

Keywords: Textile reinforced concrete, carbon fibers, repair, maintenance, high performance concrete

Over the past 25 years, the foundations for the use of technical textiles in cement-bound materials have been laid within the framework of numerous large collaborative research projects. There is a broad field of application in the area of existing buildings, mainly concrete structures. Three different goals can be differentiated here, which can be achieved with textile reinforced concrete in the area of maintenance of buildings: Strengthening of concrete structures or masonry, sealing and protecting, local reinforced concrete replacement.

The contribution first describes the composite material textile reinforced concrete with its characteristics and illustrates the areas of application. Based on this, a joint research project with the partners Dr. Auras, Institute for Stone Conservation, Mainz, Prof. Duppel, Rhine Main University of Applied Sciences, Wiesbaden, and Prof. Middendorf, University of Kassel within the framework of SPP 2255 is presented. This research project is dedicated to the development of conservation strategies and repair materials for reinforced concrete structures under engineering and monument conservation aspects. The example of the Felsberg-Berus transmission tower is used to show how a compatible and structurally dense repair mortar reinforced with technical textiles can be developed.

For questions about the theme and project SPP 2255, B3 – Aged high modernity in steel reinforced concrete. *https://kulturerbe-konstruktion.de/spp-2255-teilprojekt/gealterte-hochmoderne-in-stahlbeton-b-b3/*
Contact: E-mail *jeanette.orlowsky@tu-dortmund.de*.

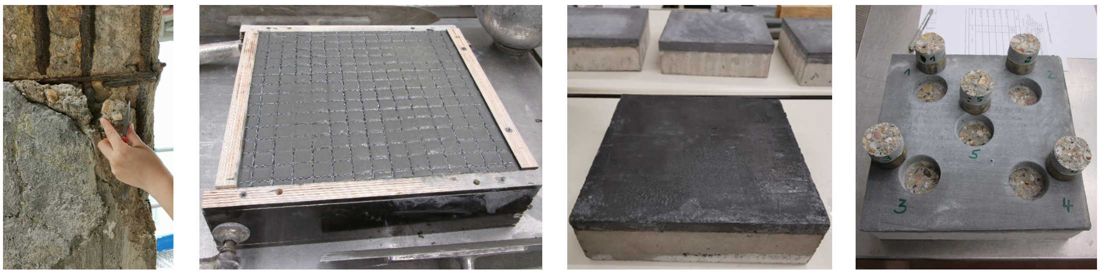


Figure 1: [Melanie Groh, Technische Universität Dortmund]

Challenges of pre-cast concrete heritage

Examples from the Netherlands

Dr. - Ing. Herdis Heineman, TNO, The Netherlands

Keywords: Pre-cast concrete; artifical stone; housing; re-use; the Netherlands.

Existing precast concrete structures are currently being reevaluated more frequently. Aiming to reduce the use of raw material and reduce CO_2 emissions pilot projects are being carried out to re-use precast concrete elements including bridges. Challenges are to demonstrate the structural safety of re-used elements under present day codes and the determine a the remaining service life.

In the context of conservation, safety and durability are relevant as well. However, additional questions arise. In recent years, more attention has been given to historic concrete and its conservation, indicating that for historic precast concrete specific problems and chances exist.

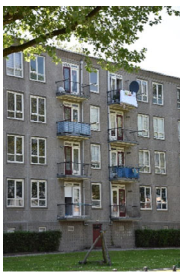
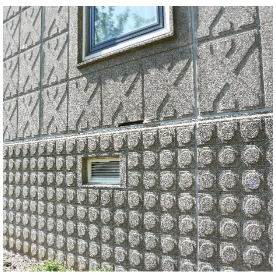
The characterization of historic precast concrete can include many facets, for example the manufacturer, the question whether elements were mass-produced or custom made, the underlying choice for precasting, or the composition of the concrete and its surface finish. Few aspects have only be investigated for specific types of elements (e.g. floor elements) or some companies (e.g., Schokbeton) yet a cmprehensive overview is still missing.

Understanding the historic context can help to evaluate the historical value of precast concrete. In the beginning of the 20th century, the potential of precast concrete was widely explored for the mass production of artificial stone. During the 1920s and 1930s, the gained knowledge with colored concrete and surface finishes was widely applied for housing projects. Parallel, an own architectural language was sought for and precast concrete offered a quality which was hardly achievable onsite. One of the first examples of large scale architectural elements is the Zoo Blijdorp (1937–1940, figure left), where the Dutch architect van Ravesteyn used coloured precast concrete elements made by Schokbeton (façade elements, windows, columns).

After the Second World War, the lack of materials and skilled workers gave rise to more precast and modular housing systems. As a group, these buildings are confronted know with increased demands of energy efficiency and living standards. Faced with the threat of demolition and hence loss of all historic fabric, alternatives are thought for including the potential of re-use of elements (figures middel).

Knowledge of the construction history of precast concrete can be beneficial to date historic objects. For example, an improvised, now obsolete shelter for railway workers made of precast concrete elements required dating as it had to be evaluated whether the object was of historic significance (figure right). Details of the reinforcement and production details gave insight that the elements were produced before 1960, yet the factory could not be identified. The object has been salvaged in order to be exposed in a museum.

The above mentioned cases only show a fraction of the variations of Dutch historic precast concrete. Chances are that due to mass production generic knowledge on identification, characterization, and conservation can be obtained, enabling to identify when historic precast concrete requires custom made approaches.


Reinforced concrete architectures of the first half of the 20th-century in Genoa

Giovanna Franco, Stefano F. Musso, Rita Vecchiattini, University of Genoa, Italy

Keywords: Conservation, Restoration, 20th century heritage, values, social inclusion.

20th Century Architecture is an Heritage at risk, caused by several factors.

It is a heritage at risk due to the short duration, despite initial expectations, of the materials with which it was built, above all the reinforced concrete which, over time, has proved to be very fragile and sensitive to the aggressions of environmental agents and, even more, to the changed climatic conditions that act even more rapidly and violently on it, often causing a deep degradation.

However, it is not so much or only the material degradation, but rather the lack of recognition of the values (material and intangible) of this heritage that generates a certain reluctance in identifying and applying adequate conservation methods to these artifacts, preferring more or less extensive demolitions.

On another side, the increase of interest and expansion of the concept of "heritage" leads us to question the values that even the most recent architecture acquires, and therefore, its eventual need of protection. It is, in fact, a heritage linked to stylistic, formal, spatial and constructive canons that are very different from the traditional ones, and which is often neglected because it was built in ways and for purposes that were soon overtaken by the epochal changes of recent decades.

It is thus a heritage subject to risks due even to lack of appreciation and care: as a living heritage it is essential to understand it, define it, interpret it and manage it well for future generations, sharing criteria and evaluation among a large community.

These cultural reflections and new research methodologies (including assessment and evaluations) have been developed within the European research project Consech20, choosing case studies in the city of Genoa (northwest of Italy). The deep analysis of these case studies, mostly of which abandoned and in search of new uses, leads to reflect on their meanings and values highlighting the essential problem of placing them in history.

These architectures have therefore been studied from different points of view in order to define a methodology of investigation prior to the intervention of reuse and conservation of material and architectural features.

With respect to exclusively technical issues and mainly related to the material conservation of such buildings and urban complexes, the research project is even based on the conviction that the heritage of the "short century" can be a vector of promotion for social integration, a training ground for experimenting with forms of monitoring and participatory decisions, involving local communities in future conservation and enhancement processes.

Research has let the richness of this inheritance emerge, in significance and value, focusing the attention from the simple materiality of the buildings to the possible modes and forms of their more total and mature interpretation.

Soldier's house 1936–1938

Grain silos "Hennebique" 1901–1906

Fruit and vegetable Market 1925–1930

Why is there a crack?

Modern inspection methods for old concrete

Dr. Frank Lehmann, Materialprüfungsanstalt Universität Stuttgart

Schlagworte: Zerstörungsfreie Prüfung, Radar, Ultraschall, Thermografie, Magnetische Streufeldmessung, Monitoring.

Denkmalgeschützte Betonbauten stammen typischerweise aus einer Zeit, in der die Standardisierung, einschließlich Richtzeichnungen, noch nicht in dem Maße ausgebildet war, wie wir es heute kennen. Darüber hinaus sind oftmals architektonisch herausragende Bauten im Fokus des Interesses, bei denen stark individuelle Herangehensweisen in der Bauausführung gegenüber Standardlösungen im Vordergrund stehen. Erstaunlich häufig treffen die Ingenieurin oder der Ingenieur bei der Beurteilung solcher Bauwerke auf die Herausforderung, dass nur wenige oder keine Bauzeichnungen und Informationen zu den verwendeten Baustoffen existieren, vorhandene Pläne von der Realität abweichen, oder die Bauwerksalterung unter den vorherschenden Lasten und klimatischen Einflüssen zu unbekannten Materialveränderungen bzw. Bauteilschäden mit unbestimmtem Ausmaß geführt haben. Im Fall von denkmalgeschützten Bauten ist es zudem ein wichtiges Anliegen, den Umfang zerstörender Untersuchungen zur Bauwerkserkundung auf das notwendige Minimum zu beschränken.

Die Triebfeder für die Untersuchung historischer Betonbauten ist idealerweise der Wunsch der Erhalt in einem weitestgehend intakten Zustand. In der Regel liegen jedoch bereits Schäden vor, die eine nähere Betrachtung notwendig machen. Für historische Bauwerke gelten darüber hinaus grundsätzlich uneingeschränkt die Richtlinien zur Bewertung und dem Betrieb von Bauwerken (z.B. die VDI 6200 oder die DIN 1076 in Deutschland). Um das Verständnis des Tragverhaltens zu fördern, den Bauwerkszustand beurteilen zu können und um die sichere Nutzung der Bauten zu ermöglichen, ist deren zuverlässige Beurteilung unter Zuhilfenahme der Methoden aus dem Spektrum der zerstörungsfreien Prüfung umso wichtiger.

Zur Lösung der bauwerksspezifischen Fragestellungen können verschiedene etablierte Prüfverfahren geeignet sein. Dazu gehören im Zusammenhang mit denkmalgeschützten Betonbauwerken z.B. die Radarmessung zur Ortung von Bewehrung und Stahlbauteilen; Ultraschall-Echo zur Ermittlung von Bauteilstärken; Infrarotthermografie zur Detektion von Feuchteeintragsstellen; Magnetische Streufeldmessung zur Beurteilung des Spannstahlzustands; Monitoring zur Überwachung von Bauwerksveränderungen; und viele mehr. Insbesondere ist die handnahe, visuelle Inaugenscheinnahme durch erfahrenes Fachpersonal aber nach wie vor die mit Abstand grundlegenste zerstörungsfreie Prüfung, auf der alle nachfolgenden Messungen mit technischen Hilfsmitteln aufbauen.

Es gilt bei der Wahl der geeigneten Prüfverfahren die jeweiligen Vor- und Nachteile abzuwägen, unter der Berücksichtigung, dass die Messdaten eines jeden einer gewissen Dateninterpretation unterliegen. Eine exakte, bildgebende Darstellung der „gescannten" Bauteilbereiche ist nur unter Laborbedingungen und mit hohem Aufwand möglich. In der tatsächlichen Baupraxis mit eingeschränkten zeitlichen und finanziellen Ressourcen sowie nicht-idealen Randbedingungen für die Messungen verbleibt in den meisten Fällen eine Unsicherheit.

Wir geben in dem Vortrag anhand von baupraktischen Beispielen einen Überblick zu einer Auswahl wesentlicher, zerstörungsfreien Prüfverfahren, mit denen historische Betonbauwerke untersucht werden können. Wir zeigen auf, welche Fragestellungen damit untersucht werden können und welche Ergebnisse aus Sicht der Auftraggeber realistisch erwartet werden können.

Why is there a crack?

Modern inspection methods for old concrete

Dr. Frank Lehmann, Materials Testing Institute, University of Stuttgart, Germany

Keywords: Non-destructive testing, radar, ultrasound, thermography, magnetic flux leakage inspection, monitoring.

Concrete heritage structures typically originate from a time when standardization, including guideline drawings, was not yet developed to the extent we know it today. In addition, the focus of interest is often on architecturally outstanding buildings, where strongly individual approaches to construction are in the foreground as opposed to standard solutions. Surprisingly often, when assessing such structures, the engineer encounters the challenge that only few or no construction drawings and information on the used building materials are available, existing plans deviate from reality, or building aging under the prevailing loads and climatic influences have led to unknown material changes or component damage to an undetermined extent. In the case of listed buildings, it is also of interest to limit the extent of destructive examinations for structural investigation to the necessary minimum.

Ideally, the driving force behind the investigation of historic concrete buildings is the desire to preserve them in as intact a condition as possible. However, damage is usually present that necessitates a closer look. In addition, the guidelines for the assessment and operation of structures (e.g. VDI 6200 or DIN 1076 in Germany) apply without restriction to historic structures. In order to enable the safe use of the structures, their reliable assessment with the aid of methods from the spectrum of non-destructive testing is all the more important. In order to improve the understanding of the load-bearing behavior, to be able to assess the condition of the structure and to enable the safe use of the structures, their reliable assessment with the aid of the methods from the spectrum of non-destructive testing is all the more important.

Various established testing methods can be suitable for tackling the structure-specific problems. In relation to listed concrete structures, these include, for example, radar measurement for locating reinforcement and steel components; ultrasonic echo for determining component thicknesses; infrared thermography for detecting moisture ingress; magnetic flux leakage inspection for assessing the condition of prestressing steel; monitoring for the supervision of structural changes; and many more. Yet, in particular, visual inspection by experienced personnel is still by far the most fundamental non-destructive test on which all subsequent measurements with technical aids are based.

When selecting the appropriate test methods, the respective advantages and disadvantages must be weighed up, bearing in mind that the measurement data of each of them is subject to a certain degree of interpretation. An exact imaging representation of the "scanned" component areas is only possible under laboratory conditions and with high effort. In actual construction practice with limited time and financial resources as well as non-ideal boundary conditions for the measurements, some uncertainty remains in most cases.

In the presentation, we will give an overview of a selection of key non-destructive testing methods with which historical concrete structures can be examined, based on practical construction examples. We will show which questions can be investigated and which results can be realistically expected from a client's point of view.

Good vs poor intervention practices on historic concrete structures

The case of Cyprus

Antroula Georgiou & Ioannis Ioannou, University of Cyprus

Keywords: concrete heritage, seismic retrofit, jacketing, confinement, externally bonded reinforcement.

Reinforced Concrete is a relatively young composite building material; yet, it has been the catalyst factor in the process of modernization of societies, and has contributed the most in the transformation of the built environment worldwide. Its ability to take any form, the ease of on site production with minimum technical knowledge and its use in the construction of multi-storey buildings have all contributed to its widespread use. Yet, the original belief that concrete would last for ever, has proven to be an illusion. Carbonation, corrosion of the reinforcement, external loads (gravity, earthquake, wind), and environmental conditions (sea side, frost), have all contributed in highlighting the defficiencies of reinforced concrete structures and their degradation with time.

A number of reinforced concrete buildings constructed worldwide in the 20th century have very recently been aknowledged as holders of historical, architectural, social and engineering values, and therefore deserve to be preserved as parts of our architectural and cultural heritage. Nevertheless, this ongoing listing process has not been extended as much as required, thus leaving many historic concrete buildings unlisted and leading inevitably to their alteration, poor repair or even demolition. Even in the case of listed concrete buildings, when extensive retrofit is required against e.g. seismic loading, the lack of relevant technical knowledge and appreciation of their values, as well as the lack of specific regulations and guidelines for the preservation of historic concrete, usually lead to the adoption of poor practices, that eventualy cause additional problems.

This presentation focuses on good and poor intervention practices adopted during the restoration of listed and non-listed historic concrete structures in Cyprus (Fig. 1), where the various repair and retrofit scenarios must include design for seismic events; this was not taken into consideration during the original design of historic concrete structures on the island, despite the fact that it is located in a seismic prone area. The interventions hereby presented (i.e., jacketing, complete replacement of reinforced concrete elements, confinement with metal parts, replacement of reinforcement cover with high performance grout material, addition of shear walls) have a construction age history span of ca. 20 years, thus allowing us to assess their performace in time and decide upon their efficiency and suitability for use in relevant restoration projects.

Figure 1: (a) Crack expansion in restored column due to expansion of corroded steel reinforcement, (b) Strengthening of column only on one side, (c) jacketing of column only up to a certain height, (d) externally bonded reinforcement of beam

From theory to practice: Degradation patterns and conservation strategies in concrete buildings built until the 1960s in the Netherlands

Gabriel Pardo Redondo, TU Delft – Architectural Engineering + Technology
Silvia Naldini, TU Delft – Architectural Engineering + Technology
Barbara Lubelli, TU Delft – Architectural Engineering + Technology

Keywords: Historic structures, Concrete, Decay patterns, Damage Process, Assessment.

Concrete used in buildings dating from the end of the XIX century to the 1960s has unique characteristics in terms of mixture and fabrication. Its use was experimental, and even more so the older the building. This is not necessarily a negative aspect. Most of the structural elements in historic concrete, for instance, were overdimensioned when compared to current standards and are still performing. However, the higher porosity and thinnercover layer of historic concrete made it susceptible to different damage processes.

Most damage processes in concrete, such as corrosion, need moisture to develop. In humid climates, like in the Netherlands, exposed concrete, when carbonated, is likely to undergo corrosion of reinforcement.

In the CONSECH20 research project 15 buildings located in the Netherlands (fig. 1) were assessed and compared with 33 buildings in three different countries (Italy, Czech Republic and Cyprus). The results indicate that the Dutch buildings have in general a better state of conservation than those examined in the other countries and that the most common damage process across countries is corrosion. The research showed that state of conservation is dependent on different factors like maintenance, continuous building use, use of sacrificial plasters. These factors are further analysed and discussed to shed light on how historic concrete buildings can be better preserved.

Figure 1: From left to right: Open-air School (1930), Radio Kootwijk (1918) and Groot Handlesgebouw (1953).