Final Program

STW Perspectief Program

Integral Solutions for Sustainable Construction (IS2C)

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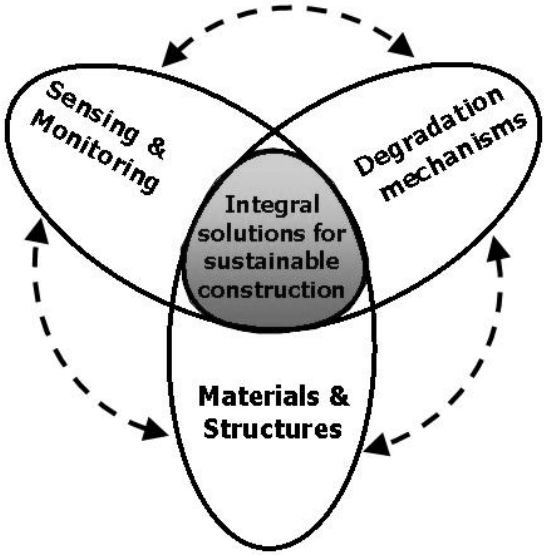

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1. Executive Summary

"Integral Solutions for Sustainable Construction" (IS2C) is a Perspectief STW program that aims to encourage new technologies and innovations on durability and service-life assessment for the building and construction sector. With the IS2C program, it is the objective to generate advanced knowledge for the elements necessary to development a next generation "*predictive SImulation Model for service-LIFE assessment*" (SIMLIFE). These elements are the building blocks for the simulation model and generate the knowledge in the field of, key performance indicators, degradation mechanisms, monitoring degradation, material / structural performance, monitoring structural performance, and data management. The program aims to attract projects that cover all together the research issues addressed above. The research projects are expected to be strongly integrated and cover at least two of the three following main research directions, i.e. Sensing & Monitoring, Degradation mechanisms and Materials & Structures and should address a level of research knowledge that goes beyond state of the art of these research directions. The IS2C program is aiming to enforce new innovations in the current state of the art of service-life assessment and to set a new standard for sustainable construction.

The origin of the IS2C program finds its basis in the collective voice of the Dutch construction industry in which they strongly request to provide a well founded basis for the (remnant) service-life assessment of our national assets. In-depth knowledge in the field service-life design and structural assessment is considered to be indispensable in order to control the risks in the maintenance and repair market and to maintain a strong competitive international position.

The Dutch construction industry is continuously challenged by new developments and criteria imposed by the asset owners but even more by the change of the global demands. Initiated by these asset owners, the desire to act as an administrator/manager of the assets, the construction industry was confronted with a significant change in the kind of the construction contracts. Modern contracts include, besides the instruction to realize a certain asset, also the order of maintenance responsibility for a predefined period, i.e. contracts with functional specifications. This holds for newly build, but also for existing aged structures that have to be maintained and/or retrofitted. This change of contracts and responsibilities has led to a strong request from the construction industry to illuminate the risks that associate with assessing the service-life of infrastructural assets.

The IS2C program aims to address the requests ensued from the construction industry in a challenging way. Projects developed within the framework of the IS2C program are demanded to comply with the integral multidisciplinary approach for sustainable construction and to emphasis the three overlapping research fields, i.e. Sensing & Monitoring, Degradation mechanisms and Materials & Structures. Combining the benefits of advanced sensing technologies and transport phenomenon-based examination of degradation processes, a substantial improvement of the current state of the art on the service-life assessment of infrastructural assets is aimed to be achieved.

In order to make the results of this research program applicable for the building and construction sector, intensive cooperation between researchers and users from private and public parties is encouraged. This also holds for participation of SMEs, Universities of Applied Sciences (“HBOs”) and Organizations for applied scientific research and other related industries or international organizations. In addition to this, a Test & Trial facility is foreseen to be developed during the course of the program that will facilitate the implementation of research results into the market.

2. Setting and Relevance

The STW Perspectief Program called “Integral Solutions for Sustainable Construction” (IS2C) aims to encourage a breakthrough in the urge to achieve a proactive prediction and monitoring system for a reliable assessment of the (remnant) technical service-life of railway and road infrastructure, and to quantify the associating repair and maintenance demands. With the IS2C program, it is the objective to generate the elements necessary to development a next generation “*predictive SImulation Model for service-LIFE assessment*” (SIMLIFE). These elements are the building blocks for the simulation model and generate the knowledge in the field of, key performance indicators, degradation mechanisms, monitoring degradation, material / structural performance, monitoring structural performance, and data management. The program aims to attract projects that cover all together the research issues addressed above and is aiming to enforce new cutting edge developments in the current state of the art in service-life assessment and to set a new standard for sustainable construction.

The IS2C program has the ambition to develop new and innovative solutions that can be used to preserve the vital part of the national economy, *viz.* our national road and railway infrastructure. In The Netherlands we are dealing with a mature stock of bridges, tunnels and other infrastructural assets that were mainly built between the 1960s and 1980s (ca. 30 to 40 years old), for which significant maintenance is to be expected within the coming decades. Besides this, in current uncertain times, governments boost their spendings in infrastructure in order to stimulate economic activities. Based on these facts, a situation has raised where durability, maintenance and (remnant) life assessment are the key issues, in view of a sustainable society.

The owners of structures always have to balance between finance and operation. For both issues they lack knowledge about the relation between the technical state of a structure and the financial and operational aspects. This lack of knowledge starts from the basis of the technical knowledge, i.e. the technical service-life performance. The knowledge of the degradation of concrete itself, and the knowledge of the relation between the actual state of construction and the repair requirements to keep the structure operational is, at this moment, not reliable enough to determine the financial consequences of structures reliably. It implies the clear demand for the need to generate more knowledge for the research issues addressed in this IS2C program.

The introduction of Design-Build-Finance-and-Maintenance (DBFM) contracts has shifted governmental responsibilities progressively towards the private sector. As a consequence,

consortia consisting of government, builders and investors are working together in Private, Public, Partnerships (PPP) and bearing long-term predefined maintenance responsibilities up to 5 to 25 years. Within the building and construction industry, this has let to the situation that infrastructural assets are judged more and more in terms of service-life assessment and less on product specifications, i.e. “functional design” versus “defined performance design”. This has turned out to be the initiation of an enormous demand for innovation within the construction industry.

The durability of traditional structures using traditional materials is relatively well covered by existing norms and regulations. Properly designed and build structures should not have major durability problems during their service-life. The major cost for a properly designed and constructed concrete structure is the replacement cost at the end of its (functional) service-life. Major financial risks for structures are caused by improper construction, bad design or flaws in building codes. Therefore, the robustness of durability predictions is an important issue. Major risks can come forward from new developments in materials, design and construction where the durability effects can not be predicted properly. At the same time, these uncertainties can be a major limitation to innovation. Research and model developments that helps to reliably quantify the risks during the service-life of structures for new developments in materials, design and construction, etc. are of issues that are of major interest to Asset Management. It was the reason to establish the Asset Management Initiative (AMI). AMI has the ambition to be the National platform for Asset Management issues and to support knowledge initiatives in the field of Technology, Process and Information. The present IS2C program will assure a close relationship with AMI and ascertain the knowledge generation for the Technology part of the AMI platform.

In order to encourage a new innovations in the area of interest, three selected research directions, i.e. Sensing & Monitoring, Degradation mechanisms and Materials & Structures, will come together in this program and will stimulate the development of innovative and integral solutions for sustainable construction. Emphasis is on the overlapping area of the three disciplines in general and on the interface between the individual disciplines in particular. New innovations in these challenging research areas will directly contribute to the competitiveness of the Dutch building and construction sectors as well as to an improvement of the ability to manage our infrastructural assets in a sustainable way. It contributes to an efficient and sustainable use of construction materials and in relation to the design life of structures and its maintenance demand.

2.1. Breakthrough in service-life assessment of infrastructural assets

The Dutch construction industry is continuously challenged by new developments and criteria imposed by the asset owners but even more by a change of global demands. Initiated by asset owners, the desire to act as an administrator/manager of assets, the construction industry was confronted with a change of kind of construction contracts, i.e. contracts with functional specifications. Modern contracts include, besides the instruction to realize a certain asset, also the order of maintenance responsibility for a predefined period. This holds for newly build, but also for existing aged structures that have to be retrofitted. Contracts wit functional specifications have entered the market pertaining to a request for retrofitting and maintenance of structures for

a predefined period. From the current state of knowledge on durability and service-life assessment and in order to realize a breakthrough among these issues in view of a sustainable society, the following main questions are addressed:

1. How to predict and assess a structures' technical service-life?
2. What is the actual state of durability and how to assess its remaining service-life?
3. What is the residual performance of existing structures?
4. How to quantify the maintenance demand in relation to the remaining-life?

In order to address these questions, the elementary physical, chemical, material, structural and construction processes underlying these questions should be elucidated in detail. To achieve this, an integral, multi-disciplinary and multi-scale research approach is necessary consisting of advanced experimental measurement techniques and numerical modelling.

2.2. Position of The Netherlands in a worldwide perspective

In view of durability design and degradation of infrastructure, the Dutch research society has a strong international reputation. Based on many initiatives that have been exploited in the past and other initiatives which are still running, the durability design approach of concrete structures has become one of the main design parameters for new construction of infrastructural assets. One of the leading documents in this respect is the fib Model Code 34 for Service-Life Design. Based on this document other leading codes and standards have been reformulated and adjusted to the durability design approach as well. Many stakeholders of the Dutch research society and industry have had major influence in the development and the accomplishment of these documents. The general vision behind the durability design is generally accepted in the construction society and forms the basis for future design of structures.

Among our three national technical universities, but also at our national applied research institute TNO, the durability design approach is the line along which research activities are exploited. Research efforts in these directions have contributed to the strong international reputation of The Netherlands in the field of durability research. Research topics like, repair technology, service-life design, sustainable, durability, new materials, multi-scale modelling, moisture movements, monitoring and sensor development are some of the topics that have lead to excellent ranking of the Dutch research groups involved in these issues.

When considering the international activities in the field of durability design and sustainable construction, numerous other countries are identified that are active in this field, among which, the USA (NIST, Princeton, FHWA), Germany (TU Dresden, TU Munich, TU Stuttgart), Norway (Sintef), China (Tongji University Shanghai, South East University, Nanjing), France (Ecole de Mines, LCPC), Austria (TU BOKU Vienna), Japan (Tokyo University, Hiroshima University). In most of these countries the focus of their research approach is covering one single issue of the durability design. In the USA, for example, they are mainly focusing on the moisture movements and scale damages whereas in Germany the research focus is on the durability of the material

itself. A coordinated effort to bridge the gap between the three disciplines that are mainly responsible for controlling the durability design is mostly lacking. The present IS2C program is addressing this integrated approach which is widely supported by the international research society and the Dutch construction industry (see Appendix 1).

International research associations, RILEM (www.rilem.org), fib (http://fib.epfl.ch), JCI-Japan (www.jci-net.or.jp/index-e.html), ACI-USA (www.concrete.org) all have addressed sustainability as a major topic within their portfolio. Besides this, many international conferences and working groups are established which have the objective to share information and experience in the field of durability and service-life prediction of concrete structures. It demonstrates the world wide interest and urgency of developing knowledge in this particular area. With the IS2C program, close cooperation is foreseen with these international associations. International Technical Committees (TCs) will be established that assure both the communication of results in an international scientific arena and, the international recognition of the results achieved from this program. This also holds for the visibility in terms of conferences, workshops and publications. All these activities will support the position of the The Netherlands as a leading country in the field of a sustainable design of infrastructural assets.

2.3. Relation with other public and privately funded programs

With the IS2C program, it is envisioned to fill-up the missing link in a long-list of already finished and many currently running activities in the field of service-life assessment and long term performance of infrastructure by introducing an integral approach. In view of the relation with public and other privately funded programs, many initiatives have been launched all with their own unique perspective, resulting in new information on a targeted field of interest. All these initiatives share the same vision, i.e. sustainable construction, in one way or another, but all lack an integral approach. The main goal of the IS2C program is to generate new innovations and to link together the three dominant research fields in this arena, i.e. Monitoring & Sensing, Degradation Mechanisms, and Materials & Structures, and to accomplish an integrated approach that will play a central role in all running activities. The individual initiatives that associate to the vision of the current IS2C program are very divers and cover a variety of research areas. A summary of these projects that are currently running are:

1. *SelfHealing Materials, 2005, SenterNovem-IOP project on increasing the durability and reliability of materials,* www.senternovem.nl/iopselfhealingmaterials.
   The IOP project on Self Healing materials is part of a National Innovative Research program. The aim of the program is to develop novel materials which have the ability to heal themselves and to strive for the regeneration of the original materials properties after having been damaged due to “internal” or “external” actions, and to contribute to the improvement of the durability and service-life of structures.
2. *RWS / TNO Built Environment and Geosciences 2008*
   The initiatives within TNO that strongly associates with the IS2C program are:

- Masterplan on Safe Civil Engineering Structures, rooted in a partnership of Rijkswaterstaat-BD and TNO Built Environment and Geosciences. The 'Masterplan's primary aim is to bring together *expertise and knowledge* for safe civil engineering concrete structures, now and in the future. As part of that, its ambition is to establish a link with fundamental work in the knowledge chain and bridge the gap between theoretical safety estimates (in structural codes) and actual performance. As such, probabilistic analysis of physical performance is a key area in the Masterplan. Probabilistic analysis finger points the key uncertainties. The Masterplan's practical scope includes new monitoring techniques to reduce key uncertainties.
- TNO innovation programs on (1) Material technology, (2) Sensor Technology and (3) Infrastructure, respectively. Main focus points in these Programs include development of new protective systems (Material technology), monitoring systems and sensor networks -in particular for civil infrastructure- (Sensor Technology) and sustainability (Infrastructure). They aim to bridge the gap between fundamental research and application, being demand-driven on the one hand and justifying TNOs participation in IC2S on the other hand.

3. *Asset Management Initiative 2008 (AMI[1] / 3TU / RWS[2]),*
   Within the AMI framework knowledge will be developed and structured about the maintenance and management of our national road and rail infrastructural assets. AMI is supported by three main disciplines: Technology, Process and Information. Each of these disciplines contributes to the development of a system for Asset Management. The main deliverables of the AMI initiative are Education, Forensics and Research.

4. *fédération internationale du béton (fib[3]) Model Code*
   The fib Model Code is the leading international document for the design, engineering and maintenance demands of concrete structures. The fib Model Code is not only written for new structures, but also for existing structures which have to be upgraded, strengthened or adapted. For the assessment of existing structures, the various aspects of service life are integrated into a consistent system based on defined performance requirements and consideration of residual service life. (http://fib.epfl.ch)

5. *Residual strength research 2009 (TUD/RWS)*
   In order to assess the remaining service-life of structures that are already in service for many years, a large experimental program has been established by the concrete structures group of Delft University of Technology in close cooperation with RWS. In order to give further input to the program and to take optimum profit of experiences in the neighbouring countries an international mirror committee has been installed, with experts from Germany, UK, France and Switzerland. The committee meets once a year in order to follow the progress of the program and to give advice for further initiatives. Information can be exchanged via international committees established by RILEM and fib.

6. *STW Perspectief 2008: Autonomous Sensor Systems.*

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[1] Additional funding is available for projects that comply with the AMI conditions, see Appendix 3.

[2] RWS = Civil Engineering Division of the Dutch Ministry of Transport, Public Works and Water Management.

[3] The International Federation for Structural Concrete (fib - fédération internationale du béton).

The Perspectief program called “Autonomous Sensor Systems” is facilitating the creation of a new generation of integrated autonomous sensors. Within the framework of this program four key research fields are identified: 1) Sensors and electronics, 2) Wireless powering, 3) Wireless communication and 4) distributed processing. Knowledge developed within the Autonomous Sensor Systems program might be used in the IS2C program and substantial cooperation is foreseen. http://www.stw.nl/Programmas/ASSYS.htm.

7. *STW Perspectief 2008: Building on Transient Plasmas*
   The relationship with the Perspectief program called “Building on Transient Plasmas”, http://www.stw.nl/Programmas/BTP/, is considered as challenging and should play a role to introduce new innovations for surface treatment and cleaning. The fundamental part of the program might have a very interesting and innovative interface with the IS2C program.

8. *Royal Dutch Shell Company: offshore sector 2009*
   In the offshore industry many activities are going on in the field of monitoring and sensing of steel and concrete structures. As a matter of course offshore platforms are designed to last for a lifetime of around 30 years in the offshore environment. In the lifetime of an offshore platform the condition is regularly monitored to ascertain the structures’ structural integrity. Key issues that are closely related to the objectives of the IS2C program are (remote) sensing, degradation monitoring, and service-life assessment.

9. *COIN, Concrete Innovation Centre Norway 2007 (Governmentally funded project*),
   COIN hopes to develop a major leap forward in advanced materials, efficient construction techniques, and new design concepts combined with more environmentally friendly material production. Within COIN, durability of concrete structures is a major topic. Service-life design based on new and actual materials data is part of this comprehensive research program.

10. *Monitoring traffic vibrations in relation to maintenance demand 2008 (Strukton/RWS/TUD)*
    At this moment, Strukton, RWS, Alliance Hollandse Bridge and Delft University of Technology are working together in a consortium on a pilot project with the main objective to examine the relationship between traffic induced vibrations and the actual bridge response. The project is aiming towards studying the influence of the external bridge actions and its consequence for the service-life performance. Close relation with the IS2C program is foreseen.

11. *DELFT CLUSTER 02.30 Smart sustainable management of concrete structures 2005-2009 (Delft Cluster/TNO/TUD)*
    The objective of this Delft Cluster project is to develop the necessary tools for a quantified and objective performance based management of concrete structures. It will do so on the basis of five work packages: i.e. service life and performance demands, establish the initial state, condition assessment, repair- and maintenance and a performance based framework for reinforced and pre-stressed concrete.

12. *European Construction Technology Platforms ECTP*
    Within the European research arena major initiatives are currently being established regarding the strategic research agenda’s (SRA). The agenda that associates closely to the IS2C program is provided by “Sustainable development of European transport networks”.

3. Research topics

3.1. Scope, criteria and focus

With the IS2C program we have the ambition to generate the elements necessary to development a next generation "*predictive SImulation Model for service-LIFE assessment*" (SIMLIFE) in view of sustainable construction. These elements should generate advanced knowledge in the field of six pre-selected research areas, covering key performance indicators, degradation mechanisms, monitoring degradation, material / structural performance, monitoring structural performance, and data management. The program aims to attract projects that cover all together the research issues addressed above. The research projects are expected to be strongly integrated and cover at least two of the three following main research directions of the IS2C program, i.e. Sensing & Monitoring, Degradation mechanisms and Materials & Structures and should address a level of research knowledge that goes beyond state of the art.

As illustrated above, a program approach which combines the efforts of experimental physicists, sensor developers, materials scientists and structural engineers are the only way to realize the ambitions of the IS2C program. For each project running under this program, it is vital that numerical/theoretical analysis is combined with experimental characterization and validation. Furthermore, to stimulate the integration of disciplines the projects should be performed with more than one research group. Only in that way a comprehensive and fundamental basis of the relevant elements for the SIMLIFE model can be obtained.

Focus
The focus of the three main research directions is:
Sensing & Monitoring: Robustness and endurance of the sensor systems.
Degradation Mechanisms: Chloride ingress and Alkali Silica Reaction.
Materials & Structures: Concrete and/or composite structures.

Not included in the scope of the IS2C program are the following issues:

- Sensing & Monitoring
  - Conventional methods of monitoring like, strain gauges, LVDT's, thermocouples, etc.
  - Table-top measurement systems with considerable dimensions and correspondingly high energy consumption.
  - Global Modelling and software development for user interfaces.
- Degradation mechanisms
  - Degradation mechanisms other than Chloride ingress and ASR.
  - Conventional experimental detection techniques, e.g. Volhard method.
  - Qualitative degradation detection, for example no visual observation and/or inspection.
- Material & structures
  - Materials other than cement-based materials.
  - Key performance indicators that are related to degradation mechanisms other than Chloride Ingress and Alkali Silica Reaction (ASR).
  - Structures other than concrete and/or composite structures.
  - Asset management issues like, economics, feasibility and risk analysis, processes information, etc.

3.2. Goal and main deliverables: Elements for SIMLIFE

The goal of the program is to generate knowledge on service-life assessment that goes far beyond the methods and procedures that are currently used in the daily practice of the construction sector. The elements to be generated within the scope of the IS2C program are the necessary building blocks for the development of the next generation simulation model that is based on an overall vision on service-life assessment, and will overrule all currently available prediction models. In order to limit the scope of the IS2C program, the dominant elements of the simulation model are pre-selected and are considered as the main research areas of this program. Furthermore, the degradation mechanisms considered in the SIMLIFE model are limited to Chloride Ingress and Alkali Silica Reaction (ASR). The IS2C program consists of the following:

Main program deliverable and the six key elements:

A predictive SImulation Model for service-LIFE assessment (SIMLIFE)

With elements:
1 - Key Performance Indicators
2 - Degradation mechanisms
3 - Monitoring degradation
4 - Material / Structural performance
5 - Monitoring structural performance
6 - Data management

In order to deal with the main research questions that have to be solved within the scope of this program and in order to be able to answer the questions raised in section 2.1, for the six research elements, the following focus description should be considered:

1 - Key Performance Indicators:
Determining the criteria at which degradation initiation occurs. Quantify the state of durability at the moment of initiation and determine the reduction of performance in the propagation phase in relation to the design parameters. Include nanotechnology and/or miniaturize sensor-based systems to measure the actual state of degradation in relation to the critical performance criteria.

2 - Degradation mechanisms:
Determine degradation mechanisms in cement based materials, limited to Chloride Ingress and Alkali Silica Reaction (ASR). Determine the critical parameters and processes that activate, stimulate and/or promote the deterioration of existing and also for new types of (blended) cements and concrete. Associated effects induced by coupled factors such as (micro) cracking due to thermal, mechanical and/or imposed deformations should also be considered.

3 - Monitoring degradation (chemical / physical):
Determine monitoring systems for measuring the actual state of degradation by using advanced sensing technologies (RFID, MEMS, Lab-on-Chip, etc) that can operate in a distributed sensor network, requiring low power supply only. The monitored actual state of degradation should provide the ability to generate feedback data from real structures to the SIMLIFE model.

4 - Material / Structural performance:

Determine the effect of degradation processes on the actual material properties and determine its effect on the residual performance of structures. Determine these effects for both existing aged and newly build and/or repaired structures. Consider the effect of “hidden” bearing mechanisms and determine the influence on the service-life assessment. Account for the effect of tolerances and non-conformities during construction on the material properties and structural performance.

5 - Monitoring structural performance (mechanical):

Determine monitoring systems for measuring the actual performance of structures using advanced sensing technologies (MEMS, etc) that can operate in a distributed sensor network, requiring low power supply only. Include the relationship between the internal effects of materials degradation the external change in structural performance. Provide the ability to generate feedback to the SIMLIFE model.

6 - Data management:

Determine a system for data management necessary to organize the input for the SIMLIFE model, i.e. input necessary to assess the service-life of structures based on the indicated degradation mechanisms, the materials and structural performance and including the feedback of data coming from monitoring / sensing of degradation mechanisms and structural performance. Include spatial effects of local monitoring. Account for the management of the expected large amounts of data generated by the monitoring systems. Include decision algorithms that account for the effect of damage and/or deterioration of the sensors and its consequences for the quality of the input data.

Towards a coherent portfolio of projects

The IS2C program aims to create a coherent portfolio of projects that deliver the key elements and contribute to the overall IS2C objective. Consequently, projects should preferably be outlined in accordance with the scheme presented in Table 1 that links the main research directions to the key elements as listed above. This scheme will function as the blueprint for the main activities and will be used as a reference to assess the fit of proposed projects in the program. To assure integration of the disciplines it is requested to address at least two main research directions and two key elements in a research project.

Table 1: Preferred outline for a coherent project portfolio.

KE / MRD	Key Performance Indicators	Degradation Mechanisms	Monitoring Degradation	Materials / Structural Performance	Monitoring Structural Performance	Data Management
Sensing & Monitoring	**X**	**X**	**X**		**X**	**X**
Degradation Mechanisms	**X**	**X**	**X**	**X**		**X**
Materials & Structures	**X**			**X**	**X**	

KE = Key Elements; MRD = Main Research Directions

4. Scientific challenges

In view of the goals and ambitions stated in the previous section, the scientific challenges addressed in this program are to come to a far-reaching integration of the research fields Sensing & Monitoring, Degradation mechanisms and Materials & Structures and to end-up with new knowledge for the six elements that are considered to be the "building blocks" of a next generation simulation model for service-life assessment that goes far beyond the current state of the art. It is encouraged that closely related topics, on which most often stand-alone individual research is conducted, will come together to come-up with an integrated approach and to exploit new solutions that look across the regular borders of individual research disciplines. Over the last decades, individual research disciplines have most often been developed very profoundly while neglecting the opportunity to discover new innovative solutions at the boarders between research fields. In this IS2C program those integrated multidisciplinary solutions are encouraged to be challenged. Taking the integral multidisciplinary approach for sustainable construction as condition of the IS2C program, enormous scientific challenges emerge from three overlapping research fields, i.e. Sensing & Monitoring, Degradation mechanisms and Materials & Structures. When combining the benefits of advanced (nanotechnology-based) sensing technologies and transport phenomenon-based examination of degradation processes, it is the aim that this approach will definitely challenge the improvement of assessing the actual state of materials durability and structural performance. With the IS2C program, high-tech scientific solutions and improved technologies will be developed that will help to an improved assessment of the condition of our national infrastructure in a most sustainable way and with the least demand of our environment.

In order to assure integration within the research proposals submitted to the IS2C program it is requested to include preferably all three, but at least two of the overlapping research fields into consideration. This also holds for the key research topics provided in the previous section, where at least two key research elements should be included in the proposal.

The state of the art of this program is illustrated by the currently applied Rapid Chloride Migration method for the experimental determination of the diffusion coefficient and the DuraCrete[4] model for service-life prediction. Both methods are still heavily criticized and the general opinion of the construction sector is that accuracy and reliability of these methods do not fulfil the demands for service-life prediction. It is therefore that there is a clear demand to learn more about the degradation cement-based materials and its effect on the performance of structures. A next generation predictive simulation model for service-life assessment is therefore to be pursued.

Scientific innovations and applicable results that are envisioned to be pursued are in the field of:

1. Resolving integral material degradation (understanding degradation mechanisms, sensor-based degradation detection and moisture driven degradation into the microstructure).

[4] The DuraCrete model was the first attempt of the European construction industry to come to a durability driven design of concrete structures. *European project Brite EuRam III.*

2. Generating the upgrading- / retrofitting-ability of existing structures (understanding the actual performance of structures, their actual state of degradation and introduce monitor and detection technologies).
3. Determine the residual performance of structures (examining and monitoring the performance of the residual strength in regard to the degradation of mechanical properties).
4. Detecting the long term performance and decay of existing aged structures (detecting the actual decay of micro composite materials expressed in terms of degradation curves).
5. Remnant life assessment (understanding the decay of materials performance in relation to the maintenance requirements)

5. Industrial Relevance & Utilization

The relevance of the IS2C program for the industrial sector is enormous. Many companies have supported the IS2C initiative by signing a letter of intent (Appendix 1). Company interests range from design firms, for deciding upon the most sustainable construction material, to Contractors, to Owners, to SMEs and to repair and assessment firms. In order to give a glance of the most recent area's at which the IS2C program will show its direct industrial relevance, four different projects have been pre-selected that show briefly the way how the program results can be embedded and/or used in practice. The projects should be shown as a selection of examples.

- ***Monitoring existing bridge behaviour: The Hollandse Bridge (Strukton/RWS)***

Recently, in The Netherlands, many bridges have encountered serious problems regarding their actual load bearing capacity in relation to its safety profile. Long term degradation processes together with increasing traffic loads were responsible for a deteriorating condition of many bridges and other infrastructural assets. One of the first bridges, where visual inspections confirmed the declining state of degradation was the Hollandse Bridge in The Netherlands (Fig. 1). It turned out that the actual load bearing capacity was insufficient for safe traffic crossing and that measures were necessary to strengthen the actual structure of the bridge. Based on this experience it was decided to develop an advanced monitoring program that should illuminate the relationship between traffic loads and environmental conditions, and the respond of the bridge in

Fig. 1: The Hollandse Bridge: Currently subject to a monitoring project.

terms of degradation. The monitoring system, called “Bridge Management System” (BMS), is an advanced way of measuring the structural bridge performance while submitted to wide number of action loads. The main objectives of the BMS is to collect data, to study the relationship between the traffic loads and the bridge response, to evaluate the traffic actions in relation to the strengthening measures, and to examine the way in which these kind of systems can be used to predict long term service-life behaviour and maintenance demands. Besides this, the system can be used to decide upon which traffic measures are necessary during maintenance operations and/or retrofitting of a bridge. The results emerging from the IS2C project would match very well with the intension of this practical monitoring project. Due to the still existing lack of knowledge in the field of materials degradation processes and structural deterioration, BMS would benefit enormously from the IS2C project. It would make long term predictions for bridge performance, up to 100 year, much more reliable.

- ***Monitoring degradation processes in the offshore industry*** **(Shell E&P)**

Offshore platforms are designed and analyzed in line with industry standards to meet, during their operational life, the performance criteria for personnel safety, corrosion, metal fatigue and structural integrity in extreme environmental conditions. During fabrication platforms are subjected to routine quality control procedures. Once installed at the offshore location, the platforms are regularly inspected above water and under water to ascertain the structure’s condition and examine if any degradation is taking place (Fig. 2). These inspections cover (1) general visual inspections for an overall impression of the structure’s condition and to establish if any gross defects are present and (2) detailed inspection for closer monitoring of the structure’s integrity. The general visual inspections under water are performed diverless, using remotely operated vehicles (ROV) and cover inspection for general damage, flooded (tubular) member detection, cathodic protection levels and corrosion, integrity of riser supports, caissons and seabed scour. The detailed under water inspection covers detection of any crack growth in the structure’s welds. Such crack growth would occur through cyclic loading effects. This inspection and monitoring is often performed using the magnetic particle inspection technique, however,

Fig. 2: Left Troll offshore production platform; Right. Inspection crew in concrete “leg”.

new developments in this field, such as considered with the IS2C program, are always strongly encouraged. With the current systems, the inspection interval ranges from 3 to 5 years for platforms in the North Sea and can be up to 10 years for platform in more benign waters, as can be found in SE Asia. Monitoring the actual performance of structures is considered as very relevant for both our steel platforms as well as for our concrete production units. In most cases the concrete structures are used in extreme conditions (Troll, Fig. 2, or Sachalin), which makes control of the actual performance of the material even more relevant.

- ***fib-Model Code for Design, Construction and Conservation of Structures (TU Delft/TNO)***

Fédération Internationale du Béton (fib) is the international organization and initiator of the widely accepted international Model Code for Design, Construction and Conservation of Concrete Structures, which is a document that is regarded as a basis for future building codes. A flow chart of the codes' service-life approach is shown in Fig. 3. It shows the various aspects that are involved in service-life design of structures and their interaction with the engineering and execution stages of a construction process. If a structure is designed, the conservation strategy

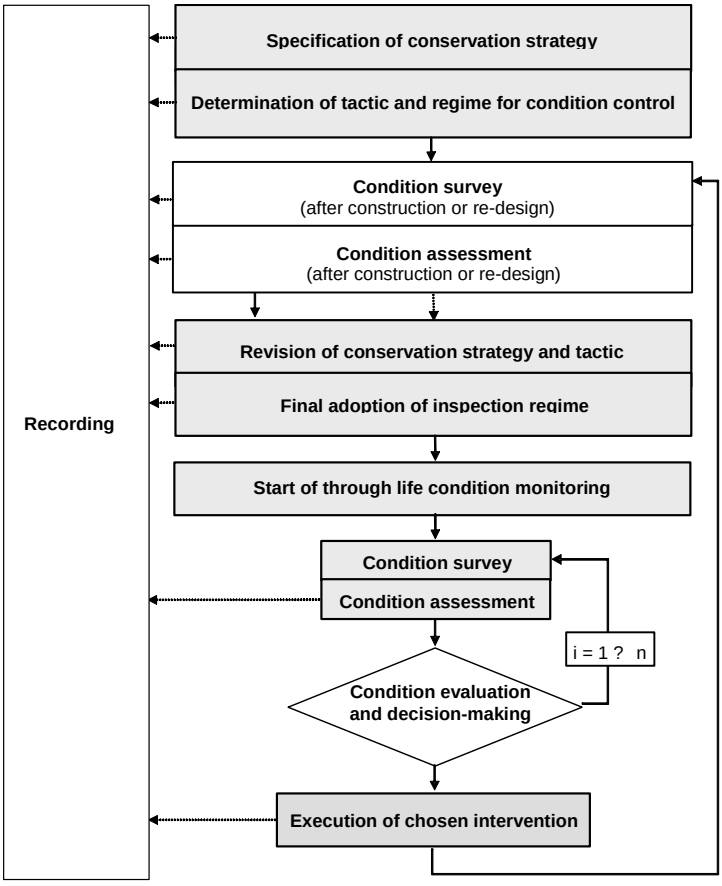

Fig. 3: Flow chart proposed for the new fib- Model Code for concrete structures showing through-life conservation process and recording of information.

should be specified. This action is the first step in the flow chart. In direct relation to this, a strategy should be developed on how the condition of the structure is assessed and followed in time: this is the second step denoted with “Determination of tactic and regime for condition control”. When a new structure is delivered, or when a plan for the remaining service life of an older structure is developed, a “condition survey” and a “condition assessment” has to be carried out. The real condition of the structures is then established for the coming period from “t = 0” and documented. The documentation belonging to this step is sometimes denoted as “birth certificate” for a new structure, or “as built document” for a new or an existing structure. On the basis of the result of this investigation the first option for the conservation strategy and tactic can be revised, if necessary, and the final inspection regime is adopted. From that moment on, the “True life” of the structure starts and should be subjected to monitoring and inspection. The observations by monitoring and inspection are compared with the expectations, which are based on the earlier evaluations, in order to see if the structure is still “on schedule”. At regular times condition surveys and assessments are therefore carried out. The results of inspection, carried out at regular times, can lead to the decision that repair or strengthening is necessary (“intervention”). If substantial repair has to be carried out the new condition has to be evaluated again (see arrow in flow chart back up to “condition survey”) and the process of assessment and monitoring and inspection starts again. In this flow chart a number of basic elements in the assessment process are ordered and their place in, and significance for, the whole process is visible. In order to make full profit of the procedures sketched in the flow chart, sufficient knowledge is necessary in a number of areas associating very closely to the goals and ambitions of the IS2C program and makes the program very valuable for the development of the internationally accepted Model Code. A glance of the areas are:

- predicting the deterioration of structures due to chemical / physical processes
- determining the real bearing capacity and condition of older structures, including “hidden” load bearing mechanisms for the taking-in those structures into the system
- definition of criteria to be regarded in “birth certificate” or “As-built” documents
- development of appropriate inspection and monitoring techniques
- development of appropriate technology for refurbishment

- ***Monitoring systems available for degradation processes*** **(MESA+)**

Knowledge about the composition and microstructure of concrete is generally available from lab research and off-line analysis of small test samples. *Lab-scale* monitoring of the relevant parameters such as water content, temperature and specific chemical composition of the structure (such as Cl^-) is often required for validation. Data obtained from these non-destructive measurements, at precisely controlled and evoked laboratory conditions can lead to accurate and optimize model predictions for, e.g. degradation mechanisms.

Sensing and monitoring existing infrastructure manifests itself in logging its actual performance providing feedback to predictive models for degradation. Properly acquired sensor data can either correct and adjust some of the (ageing) parameters in the open-loop model in accordance with the actual condition of the infrastructure or even directly predict, or at least refine, the moment of inevitable servicing and maintenance of the infrastructure. The IS2C program provides the opportunity to develop the sensors and communication systems that make monitoring of the

actual performance of structures very feasible. Challenging research questions evolving from the use of sensors in existing or new infrastructure and, which in essence, are also part of IS2C program, are:

- the life time of these sensors (and thus their physical and chemical robustness) is an important issue requiring thorough research. Either very stable, drift-free operational principles have to be chosen or *in situ* calibration facilities must be present, nowadays possible in Lab-on-a-Chip systems comprising both sensors and calibration sub-systems.
- in many cases distributed sensor networks might be required to optimally predict the condition of the concrete infrastructure. Both the communication of the sensor nodes in the network itself and the communication to the outside world (the data processing systems) is an interesting topic of research.
- a very interesting topic is that of the power supply of the sensor (network). The choices for passively operating sensors with a passive read-out or for sensors that are activated from the outside world (like RFID, MEMS devices) are possibilities. More interesting even is trying to find local sources of power in the infrastructure itself, like vibration (to be harvested by piezo-electricity) or temperature (peltier elements).

- ***CUR Building & Infrastructure 2009***

The work being performed within the IS2C-program will lead to a major step forward towards an integral approach of service life (re)design and will contribute to a sustainable built environment. As one of the representatives of the sector CUR expressed their interest to facilitate the realization of the actual "*predictive simulation model for service-life assessment*" (SIMLIFE) as a envisaged follow up of the program. The various projects that will run under the IS2C program will lead to important results which can be seen as the "building blocks" of an integral approach and a set of (sub-)models. The logical following step is to bring together all these building blocks from IS2C (and related work by others) towards one integral model for service life design of concrete structures

6. Coherence and Knowledge Transfer

In order to achieve maximum cooperation and coherence among the projects submitted to the IS2C program a workshop has been organized in December 2008 (Appendix 2), with representatives from the university and industry. Participants covered the three dominant research directions of the IS2C program, i.e. Sensing & Monitoring, Degradation mechanisms and Materials & Structures and unanimously support the goals and ambitions of the IS2C initiative. In order to maintain support and to stimulate communication among the participants, knowledge transfer between the different projects is considered to be of utmost importance. Therefore, the following initiatives will be considered with respect to coherence and knowledge transfer of the IS2C program and will be initiated by the Program Committee:

With respect to the proposals:

1. Projects should be multidisciplinary, i.e. a combination of at least two out of the three main research disciplines, which are Sensing & Monitoring, Degradation Mechanisms

and Materials & Structures, have to be considered. Table 1 provides the reference. Single topic projects will not be considered.

2. Proposals should consider both numerical modelling and experimental research work.
3. The Program Committee will assess, evaluate and rank the pre-proposals regarding their relevance and contribution to the general IS2C program deliverable and will advise applicants of full proposals to shape their proposal in view of interaction with the other projects.
4. Full proposals will be internationally peer-reviewed with respect to its scientific quality and utilization perspective and ranked by an independent expert jury.
5. The Jury will evaluate the full proposals on scientific quality, the utilization perspective and the strategic fit within the program.
6. In addition to the Jury ranking, the Program Committee will advise the STW board on the cohesion between the ranked project proposals and their relevance for the program (see Table 1).

With respect to the projects:

Program steering committee

7. After the official start of the IS2C program, the Program Committee will alter its responsibilities from a supervision perspective into a program steering committee to safeguard progress, excellence and coherence.
8. The program steering committee will organize annual meetings with all project leaders to discuss the progress of the individual research projects and the overall progress of the IS2C program while considering new opportunities for cooperation between the projects.

Users committee:

9. Installation of users committees for the individual projects.
10. Coordination of the interactions between the users committees of the different projects.
11. Attending the users committee meeting of each project by one of the members of the Program Committee.

With respect to the dissemination and under supervision of the Program Committee:

12. An international kick-off symposium is organized after commencement of all the projects.
13. Annual IS2C workshops for the exchange of knowledge and to stimulate cooperation take place.
14. A web-site will be organized where all the projects present their projects and results.
15. A CUR committee is launched for bringing together all the project results in order to set out the follow-up directions for the envisaged “predictive SImulation Model for service-LIFE assessment” (SIMLIFE-model). Besides this, CUR will actively organize the dissemination of the research results into the Dutch building and construction sector.
16. The initiative is introduced to the international research societies like RILEM, FIB, ACI and participation in Technical Committees for discussing and communicating the research results.

17. A Test and Trial (T&T) facility is shaped during the course of the program. The T&T facility will be established and operated by an expert board with representatives from universities, industrial partners and RWS participating in the IS2C program. The T&T facility will serve as a communication platform and provide the opportunity to overcome the gap between research institutes and the building practice.
18. Other industrial partners will be invited, new consortia and SME-branch organizations will be involved and informed about the above mentioned dissemination events.
19. Interactions with MKB (MKB Nederland), Bouwend Nederland, Concrete Construction Industry and HBO organizations will be intensified. Intensive cooperation is foreseen with the HBO RAAK-PRO initiative on “Condition Based Maintenance”, which is currently in the application stage.

7. Organization of the program and budget

For the details of the time planning, proposal application and selection process please see the call for pre-proposals.

7.1. Proposals and selection

The selection of the proposals will be done in two steps: a call for pre-proposals and an invitation to the applicants of the pre-proposals to submit full proposals. The pre-proposals will be evaluated and selected by the Program Committee, and applicants will be informed about the conditions to submit full proposals. After an eligibility check of submitted full proposals by the STW office, the second step includes an international peer-review with respect to scientific excellence and utilization perspective and a subsequent evaluation and ranking by the Program Committee. This final evaluation explicitly addresses the fit of the full proposal in the program (according to Table 1). On the basis of this, the Program Committee advices the STW board on funding. The STW board will decide upon the funding of the proposals.

7.2. Duration

In order to accomplish a multi-disciplinary approach for the proposed IS2C program, a duration of 6 years is allocated. This period enables the possibility to shift research projects in time and to ensure overlap between the individual research projects and to achieve a successful cross-fertilization among the different research disciplines. For this reason, the projects should be scheduled in such a way that clear milestones can be described and that (strong) bonds between related projects can be achieved as well.

7.3. Budget

For this call a budget of M€ 6 is required. A contribution of M€ 4.5 will be made available by STW and the remaining M€ 1.5 must be matched by contributions of potential technology users (companies / institutes). The maximum of project costs that can be requested from STW is € 750.000 per project. A contribution of potential “users” of at least 25% of the total project budget

is compulsory and adds up to the requested amount from STW. The users do not have to co-finance up-front in the program but may contribute in-kind (materials, equipment, facilities, etc) and/or financially in the project wherein they will participate.

The present IS2C program will have a close relationship with the Asset Management Initiative (AMI) and ascertain knowledge generation for the Technology part of the AMI platform. Therefore, AMI has committed itself to the IS2C program by offering financial support. The additional funding is available for projects that comply with the AMI conditions, see Appendix 3.

A total amount of k€ 70 will be reserved for program activities in order to strengthen the IS2C community. This budget will be used for the organization of the kick-off symposium, the annual workshop, a professional website, and the organization of meetings to coordinate and strengthen collaboration in the program. This funding will be made available by the STW board upon advice of the Program Committee. All other costs for the participating groups should be incorporated in the project budget plan.

7.4. Program Committee

- **Dr. ir. E. Koenders, program Chairman**
  Faculty of Civil Engineering and Geosciences, Delft University of Technology
- **Prof. Dr. ir. O. Adan**
  TNO / Faculty of Applied Physics, Eindhoven University of Technology
- **Ir. J. Bakker**
  RWS Bouwdienst Rijkswaterstaat Utrecht
- **Dr. ir. T. van Beek**
  VOBN, Veenendaal
- **Prof. Dr. ir. A. van den Berg**
  MESA+ / BIOS, University of Twente
- **Prof. ir. A. van der Horst**
  BAM Infraconsult / Faculty of Civil Engineering and Geosciences, Delft University of Technology
- **Prof. Dr. J. Kok**
  Institute of Advanced Computer Science, Leiden University
- **Ir. J. Mijnsbergen**
  CUR Bouw en Infra, Gouda

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Appendix 1. Company support

Thus far a large number of companies have expressed their interest to participate in the IS2C program by signing a letter of intent, by joining the workshop or by contributing to the IS2C program call. The table below gives an idea of the current users interest in this program. This list is open for other parties who want to join in this program.

Table: Users with confirmed interest in the program

Company	Expertise
ABT	Engineering firm
BALLAST NEDAM	Building contractor
Royal BAM group	Building contractor
Bouwend Nederland	Branch organization for Dutch contractors
Cement en Beton centrum	Branch organization of cement producers
CONSENSOR	Innovative SME for measuring instruments
CUGLA	Chemicals and additions company
CUR Building & Infrastructure	Valorization institute for the Building and Construction industry.
ENCI	Cement producer
G4	Municipal engineering firms of Utrecht, Amsterdam, Rotterdam and The Hague.
Hurks beton	Prefabrication industry for concrete elements
INTRON	Consultancy institute for the Building and Construction industry
MOVARES	Railway engineering firm
N.V.D.O.	Branch organization for maintenance industry
NEBEST	Inspection and survey
Philips applied technologies	Electronics company for Mechatronics, System in Package and Digital systems
ProRail	Owner of Dutch railway infrastructure
RWS	Owner of Dutch road infrastructure
Shell	Oil exploration and production company
STRUKTON	Building contractor
TNO	GTI / Applied research institute
VOBN	Branch organization for in-situ concrete production

Appendix 2. IS2C workshop participants

On December 9th, 2008 the IS2C program initiators organized a workshop to bring together experts from Dutch academia and industry. In the workshop the framework of the IS2C program has been discussed. This meeting brought together industry and academia which of some were unfamiliar to each other. The following experts participated in the workshop.

Name	Organization	Material Structures	Degradation Mechanisms	Monitoring Sensoring
dr.ir. E.A.B. Koenders	TUD			
prof.dr.ir. O. Adan	TNO/TUE		X	
dr.ir. W. Olthuis	UT			X
prof.dr.ir. P. French	DIMES			X
prof.dr.ir. H.J.H. Brouwers	University of Twente		X	
Dr.ir. J. Frenay	ENCI/Heidelberg		X	
ir.drs. J. Verlaan	TUD	X		
drs. W. Stenfert Kroese	Consensor			X
prof. dr. J. Kok	Liacs			X
prof.dr. R. Meijer	TNO-TPD			X
Erik Puik	Hogeschool Utrecht / TNO			X
Gert-Jan Temmink	Hogeschool Utrecht	X		
dr.ir. C. Meuleman	STW			
dr. C. Mombers	STW			
Prof.dr.ir. K. van Breugel	TUD	X		
Mozafar Said	Gemeentewerken Rotterdam	X		
ir. J. Gulikers	RWS Bouwdienst		X	
Jan Heuveling	VOBN		X	
ing. B. Obladen	Strukton	X		
ir. J. Mijnsbergen	CUR Bouw en Infra	X		
ir. D. Verheul	MOVARIS	X		
ir. A. van 't Zelfde	BAM	X		
prof.dr.ir. K. Kopinga	TUE		X	

Appendix 3. Additional funding (AMI)

Asset Management Initiative (AMI) is established as a 3TU and RWS initiative with the ambition to be the National platform for Asset Management issues and to support knowledge initiatives in the field of Technology, Process and Information. AMI has thorough company support and aims to establish a facilitate communication and discussion within a national company network. The present IS2C program will be associated to the knowledge generation for the Technology part of the AMI platform. It is therefore that additional funding can be requested whenever contributing to the ambitions of AMI.

Additional funding is available from the AMI matching budget. Projects can apply for additional funding up to a maximum of 7,5% of the total project costs. Projects that request for AMI matching funding should comply with the AMI criteria. The criteria relate to the projects deliverables of the IS2C projects and have to be produced in addition to the IS2C deliverables. In order to request for AMI matching funding at least 4 out of 6 of the following issues should be accounted for explicitly in the project proposal. If not all the criteria are met, funding might be assigned propositionally:

1. Clear description of the practical relevance;
2. Applicability of research results to real structures;
3. Relevance to economically efficient exploitation of infrastructure, from life cycle point of view, i.e. a reduced maintenance perspective;
4. Relevance to an improved accuracy of the process of degradation;
5. Relevance to the control of the technical service-life of structures;
6. Relevance to sustainability, i.e. reduced material usage in construction.

Procedure

- Indicate explicitly in the IS2C project pre-proposal if AMI matching funding is requested.
- Indicate clearly how to comply with the above listed AMI criteria.
- Indicate the requested amount AMI matching funding.

Selection and Assignment

The selection and judgment will be based upon the pre-proposals submitted to the IS2C program. Assignment of the AMI matching funding will be judged by the members of the Program Committee. Project applicants will be informed about the funding assignment together with the IS2C pre-proposal notification. The funding will be made available proportional to the duration of the project.