INSITER INTUITIVE SELF-INSPECTION TECHNIQUES

# Recommendations for standardisation

Deliverable report D6.2

**Deliverable Report: D6.2, issue date on 16 November 2018**

**INSITER - Intuitive Self-Inspection Techniques using Augmented Reality for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components.**

This research project has received funding from the European Union's H2020 Framework Programme for research and innovation under Grant Agreement no 636063.

# Recommendations for standardisation

Deliverable report D6.2

| | |
|---|---|
| Issue Date | 16 November 2018 |
| Produced by | Work Package 6 Team (WP leader ISSO) |
| Main authors | Jan Cromwijk / Arjan Broers (ISSO) |
| Co-authors | Jan-Derrick Braun (HVC),<br>Richard Deighton /Ruud Geerligs (DMO)<br>Peter Bonsma (RDF)<br>Jacques Cuenca (SISW)<br>Gian Marco Revel / Milena Martarelli (UNIVPM)<br>Pedro Martín Lerones (CARTIF)<br>Carlos Bárcena (DRA)<br>Gaby Abdalla (DWA), |
| Version: | Final |
| Reviewed by | FHGIPA and DRAGADOS |
| Approved by | Ton Damen – Project Coordinator (DMO)<br>Rizal Sebastian – Technical Coordinator (DMO) |
| Dissemination | Public |

## Colophon



This research project has received funding from the European Union's H2020 Framework Programme for research and innovation under Grant agreement no 636063.

# Fulfilment of the Description of Action (DoA) in D1.6

### Accessibility of this deliverable: Public

This deliverable is presented in 1 part:

Report / documentation (this document)

### Fulfilment of WP, Task and Deliverable scope and objectives

| Summarised objectives as stated in DoA | Results presented in this deliverable |
|---|---|
| WP 6 scope and objectives:<br><br>To ground the innovative results from the INSITER research project in real practice in the construction sector by way of:<br><br>• internalisation (enabling the targeted users of INSITER results and incorporating the INSITER solutions within the organisation and project workflows, and embedding INSITER solutions in guidelines, norms and standards);<br>• Externalisation (creating the common ground / acceptance in practice, promoting INSITER solutions to a wider audience, and paving the way towards implementation and exploitation in the market). | Addressed (please explain to which extent):<br><br>• Embedding INSITER solutions in norms and standards as for recommendations that focus on applying standards.<br><br>Addressed in conjunction with other deliverables:<br><br>• incorporating the INSITER solutions within the organisation and project workflows is part of (and addressed in) D6.1.<br>• Creating common ground and acceptance in practice is done by external communication and dissemination in D6.4 and D6.5.<br>• Promoting the INSITER solutions is part of dissemination (D6.5) while the implementation and exploitation is described in the business plan of D6.6. |

| Summarised objectives as stated in DoA | Results presented in this deliverable |
|---|---|
| Task 6.1 scope and objectives:<br><br>• Formulating recommendations for standardisation, and providing input to the relevant working committees for the development of practical guidelines, technical norms and standards:<br>• International comparisons of standard formulation, implementation practices and outcomes.<br>• Developing and maintaining expertise within government and institutions / the use of external advice (national building research organisations, universities, consultants).<br>• Supporting use of the national, EU and international collaboration in standardisation procedures (for example: NEN [Dutch Normalisation Institute], CEN [European Committee for Standardisation], ISO [International Standardisation Organisation], especially addressing EPBD (European Energy Performance of Building Directives) towards achievement of EU2020 goals.<br>• Contribution to open standardisation in BIM through BuildingSMART by active roles of INSITER consortium partners in the EU and regional chapters / working groups.<br>• Publication of practical guidelines for construction companies and projects, translated and distributed in EU countries where INSITER consortium partners are present. | Addressed (please explain to which extent):<br><br>• Recommendation for standardisation based on used norms and standards during INSITER research.<br><br>Addressed in conjunction with D1.1.<br><br>• Expertise is developed and obtained from research organisations, universities and consultants in this and most other tasks.<br>• For research purposes the main focus has been EU and international standards. National standards have been included where useful (e.g. the Dutch NEN 2767)<br><br>• Developed in conjunction with WP4. Multiple consortium partners have active roles in other EU projects (e.g. ISSO in BIMplement)<br>• The practical guidelines is visualised in conjunction with WP1 and WP3 by the INSITER Guideline Mobile App, and available in English. |
| Deliverable D6.2 scope and objectives:<br><br>• This is a result from task T6.1. Reflection will be made on existing guidelines and standards to extend the preliminary list. Targeted standardisation areas –including building engineering and energy, quality management, ICT and BIM, as well as procurement. | Achievement percentage: 100%<br><br>Specific results fulfilling the deliverable objectives:<br><br>• Reflection on guidelines and using the INSITER methodology for quality assurance (energy, quality management)<br>• Recommendations for data exchange and BIM interoperability |
| • Self-inspection methods (i.e. procedures, protocols, manuals) as well as assessment and calculation methods are presented as input for EU normalisation or standardisation. | Achievement percentage: 100%<br><br>Explanation: Recommendations for standardisation of quality improvement in the construction sector. |

# Publishable executive summary

This deliverable is part of work package 6 ‘Training, communication, dissemination and exploitation’. It is documenting the recommendations for standardisation concerning the executed work within INSITER. The recommendations are categorised in chapters, related to:

- Chapter 2: Building Quality control and certification;
- Chapter 3: Data interfaces between different equipment;
- Chapter 4: BIM open-interoperability;
- Chapter 5: Procurement;
- Chapter 6: Guidelines.

For building quality control, different countries have different rules and regulations. That makes it difficult to follow a default approach. Although different, the main similarity is that the ever growing complexity of buildings creates a demand for a more prominent role for inspection parties. New development around quality assurance in the Netherlands, the upcoming “Quality Assurance Act for construction” makes a move for private parties to control the building process. In the current situation the government institutions (municipalities) are responsible for quality control.

Concerning measurement equipment, IR thermograph will be exploited for the U-Value distribution assessment and thermal bridges localisation during the building process. For this purpose an excitation procedure is designed to produce controlled thermal gradients between the wall surfaces and induce a thermal heat transfer across the wall. The results of the sub-task will be a standardised procedure and prototyping using different commercial IR systems that allow storing thermal data in open formats.

The number of formats in which measurement data is expressed tends to grow and evolve according to specific (and often conflicting) needs in terms of completeness, readability, portability, redundancy, etc. As proprietary file formats are developed, for instance in the private sector, software interoperability based solely on file input/output is at risk. Therefore, the file formats have to be discussed and agreed upon.

The main barriers to the application of measurement equipment for INSITER purposes are related to the commercial systems available in the market and to their applicability on-site during building construction.

One of the challenges to carry out self-inspection is the lack of interoperability between the various equipment used. Devices and current tools deployed on-site do not speak the same language, which leads to a lack of communication. Therefore, INSITER presents a framework under which the equipment is able to send information in a common format. Within the world of Information Technologies (IT), there is an ever-growing number of information exchange standards. The existing standard(s) may not fulfil the needs and requirements, and could possibly require the combination of several standards. For projects like INSITER, the choice regarding exchange standards is straightforward. There is only one open standard (IFC, also called ISO16739) that is widely accepted, mature and covers most of the disciplines within the sector.

For the use of INSITER in construction project, it is important to have a procedure of establishing what is to be procured. Not only the building and its performances must be described, but far more interesting are the requirements related to planning, execution, inspection and evaluation. In other words, how the desired performance will be assured. At aspects where the procedures related to the construction objectives are generic, standardisation may be useful.

INSITER's guidelines involve the 8-step methodology as proposed in the DoA. This methodology is developed to cover the full aspect of performance based evaluation and quality assurance. At the contrary, existing standards, like the standards for condition assessment, only have a focus on component conditions and not the functional embedment in the greater system and entire building. The proposal for a standardised approach would be the continuous consolidation of small and large scale construction processes through the (O)PDCA (observe, plan, do, check, act) approach. Self-inspection demands understandable and applicable inspection protocols. Besides specific product-related inspections, there's a wide range of generic inspection protocols that can apply to a certain component or element. It would be an added value to have these protocols standardised by branch organisations, in order to have a widely accepted inspection list for assuring quality.

# List of acronyms and abbreviations

| | |
|---|---|
| AES | Advanced Encryption Standard |
| AR | Augmented Reality |
| BIM | Building Information Modelling |
| CAD | Computer-aided design |
| CEN | European Committee for Standardisation |
| CMO | Concept Modelling Ontology |
| DEPs | Data Exchange Plans |
| DoA | Description of the Action |
| EPBD | European Energy Performance of Building Directives |
| EPC | Energy Performance Contracting |
| HVAC | Heating, Ventilation, Air Conditioning |
| IFC | Industry Foundation Classes |
| IR | Infrared (used for thermal imaging) |
| ISO | International Standardisation Organisation |
| PBC | Performance based contracting |
| PDCA | Plan Do Check Act |
| QA | Quality Assurance |
| QC | Quality Control |
| SOFA | Spatially Oriented Format for Acoustics |

# Definitions

### *BIM-based simulation of processes*

Refers to simulations that uses BIM-based 3D models and associated work plans to visualize process sequences and construction or assembly steps among other issues like maintenance or inspection processes. In the context of INSITER the focus is on BIM-based simulation of processes for self-instructions purposes.

### *KPI – Key Performance Indicator*

A performance indicator or key performance indicator (KPI) is a type of performance measurement. KPIs evaluate the success of an organization or of a particular activity (such as projects, programs, products and other initiatives) in which it engages. [Wikipedia]

### *Self-inspection*

Encourages, enables and equips construction workers to check their own working processes and the results respectively, both individually as well as peer-to-peer with other workers.

### *Self-instruction*

Is a pro-active approach to provide craftsmen and professionals with interactive guidance during their working processes. Self-instruction is facilitated on the workers' mobile devices, with continuous updates based on both pre-planned (designed) process as well as real-time feedback from self-inspection. Self-instruction prevents wrong actions, and helps the workers to rectify any error immediately.

# Contents

# 1. Introduction

Goal of INSITER is that the INSITER self-inspection solutions can be applied and standardised for all geographical regions in Europe. To reach that goal INSITER applied the use of universal hardware instruments; open-interoperable software and data models. When doing this boundaries are crossed, new innovations (calculations, algorithms and measurement tools) are developed and barriers in standards, norms and references have been found, addressed and resolved or walked around.

International, European, national and regional norms, standards and references for both products and construction processes are during the INSITER project included in INSITER software, data and analysis models. When doing this several aspects have been found that are translated into recommendations for standardisation. INSITER provides these recommendations as input to standardisation in the areas of: building quality control and certification, data interfaces between different equipment, BIM open-interoperability and procurement. Also some of the in INSITER developed self-inspection methods (i.e. procedures, protocols, manuals, guidelines) as well as assessment and calculation methods are presented as input for EU normalisation or standardisation. In the interest of obtaining real energy-efficient buildings, it is desirable to create feedback-loops from self-inspection on-site to the design actors and when needed quality standardisation committees. Some reflections on these will be added at the end of the project.

When results are incorporated in a standard, the beneficiary concerned must ask the standardisation body to include the following statement in (information related to) the standard: *"Results incorporated in this standard received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 636063".*

## 1.1 Objectives and target groups

Objective of this deliverable is to provide input to standardisation in quality control and certification, data interfaces between different equipment, BIM open-interoperability and procurement.

Target groups are: normalisation and standardisation committees at regional, national, EU and international level; governmental bodies such as housing ministries, equipment providers, BuildingSMART and BIM developers.

Local municipalities and the responsible departments for supervising building quality, energy audit and building permit are involved through the professional activities (i.e. real building projects) of all industrial partners in the INSITER consortium. They have been consulted during preparation of recommendations for standardisation in quality control protocols to be applied at regional, national, EU and international levels.

## 1.2 Main achievements and limitations

Results of this deliverable include the reflections and recommendations made on the different subjects:

- Building quality control and certification;
- Data interfaces between different equipment;
- BIM open data interoperability;

- Procurement;
- Guidelines for quality improvement.

For INSITER we used the following approach: Existing norms and guidelines were taking into account for the above mentioned subjects and checked for the relevance of INSITER. The results of the INSITER research can be used as proposals to improve existing norms and guidelines or even as a starting point for new norms and guidelines. These proposals have a focus on the supplemental value of INSITERS work in the European construction market.

A final conclusion is made by identifying the barriers found during INSITER research.

## 1.3 Positioning of this deliverable

This document, D6.2, is the second deliverable of task 6.1. For development, it relies on the input from all development work packages and the pilot-cases. This is shown in Figure 1.

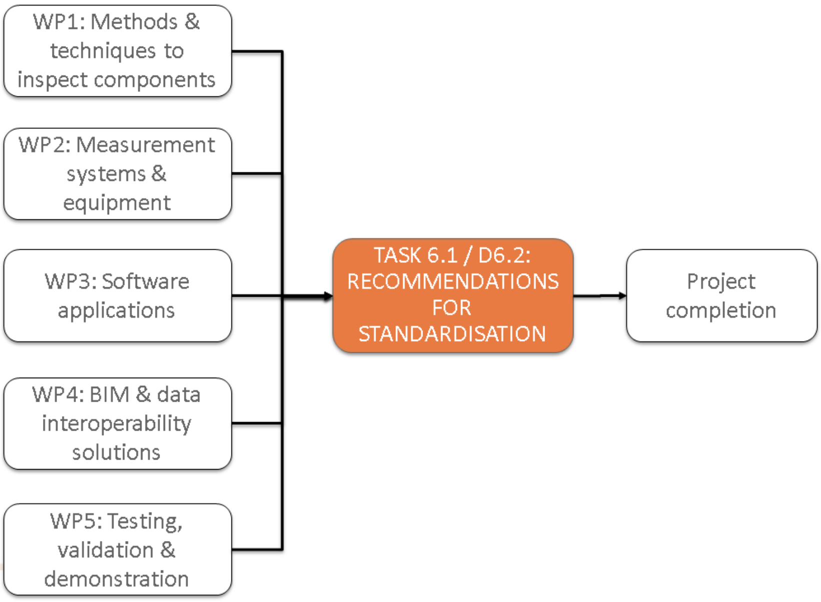



Figure 1: Input and output of task 6.1 – D6.2

# 2. Building quality control and certification related

In this chapter standardisation and normalisation related to the building quality control and certification are addressed

| International | European | National | Regional |
|---|---|---|---|
| | | | |
| Supporting use of the national, EU and international collaboration in standardisation procedures (for example: NEN [Dutch Normalisation Institute], CEN [European Committee for Standardisation], ISO [International Standardisation Organisation], especially addressing EPBD (European Energy Performance of Building Directives) towards achievement of EU2020 goals. | | | |

## 2.1 Applied norms, standards and references

Related standards in CEN (European standardisation)

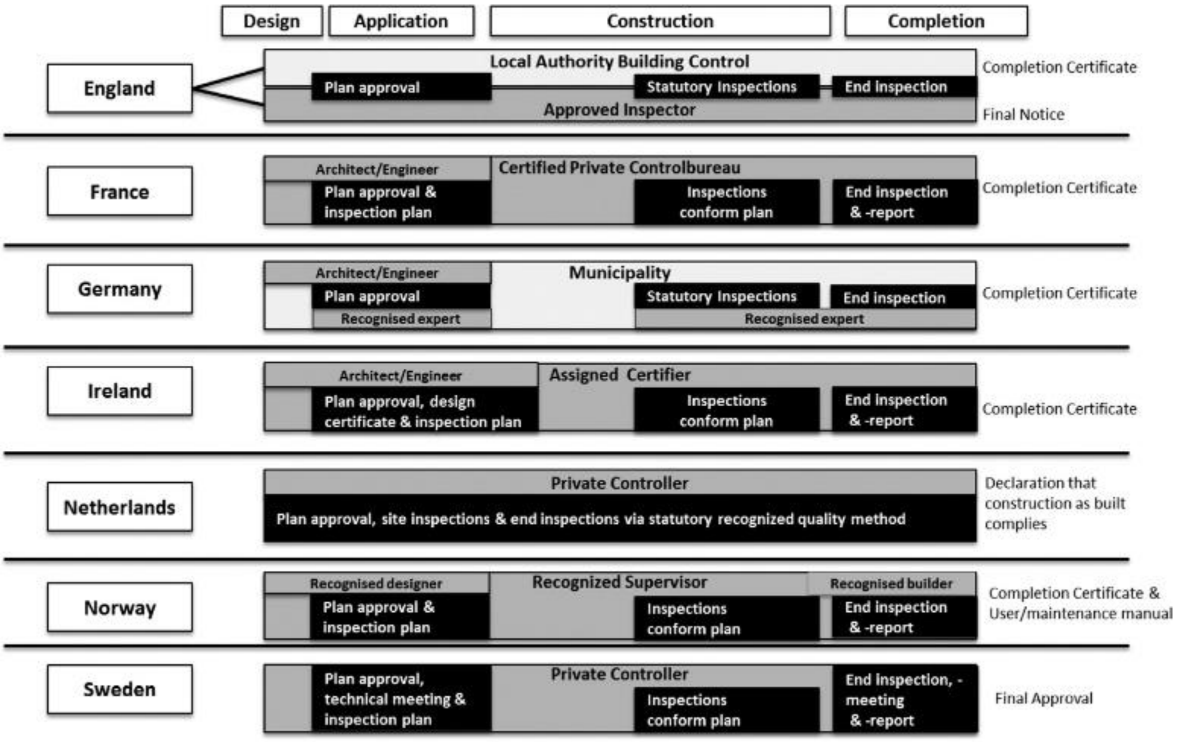
EN 15239 - Ventilation for buildings - Energy performance of buildings - Guidelines for inspection. August 2006.

EN 15251 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. July 2007.

## 2.2 Opportunities for standardisation

The general rule in all countries is that all constructions have to meet the requirements set in the building regulations. These requirements demand for a range of issues (from fire safety to sustainability) and building components (e.g. stairs, windows and ceiling height) a minimum quality level. All constructions must meet these minimum demands. However, in practice, most constructions are not (fully) processed through the statutory quality control procedure. In practice, only complex constructions are eligible for a full quality control procedure. Besides that, all countries have a list of exemptions and constructions that can be notified to

In (i.a.) Germany, England, France, Ireland and Sweden quality control systems are used in the construction sector. In these countries, the responsibility for showing that the building regulations are met lies largely by the private parties.




**Source:** Meijer and Visscher, 2016

Figure 2: Main characteristics of the regular quality control procedure in seven European countries [2]

Figure 2 summarises the main characteristics of the regular quality control procedure for constructions in seven European countries. The figure pictures the statutory quality control procedures to check whether the technical demands set in the building regulations are being met. The Dutch system shows the proposed new Quality Assurance Act. Furthermore, checks on the planning, zoning and aesthetics requirements are not included. In all countries (local), authorities are responsible for these planning approval procedures.

The central part of the figure gives an overview of the legal quality control procedures and parties responsible, between the phases of the construction process. A grey colour means that private building professionals are involved and responsible; white indicates local authority involvement. The black rectangles show obligatory elements within the quality control procedures.

Private parties play a dominant role in the regular quality control procedure (see also Figure 3). This starts with the role of the architect in the designing phase. The figure shows that sometimes registered architects must be involved or meetings have to be arranged and inspection plans must be made. Site inspections are obligatory during construction. Sometimes reference is made to the inspection plans; sometimes certain construction moments or construction elements are mentioned. The quality control procedure ends in all countries with an end inspection. Constructions can only be taken in to use when a completion certificate (or final approval) has been issued.

| | | |
|---|---|---|
| England | Approved Inspectors | Accreditation and supervision by Construction Industry Council |
| France | Private control bureaus | Certification and supervision by National Accreditation Body COFRAC |
| Germany | Architects, engineers and recognized experts | Registration and supervision by Professional organisations/bodies |
| Ireland | Assigned certifiers | Registration and supervision by Professional organisations/bodies |
| Netherlands | Quality control instrument | Recognition and supervision by National Admittance Organisation |
| Norway | Responsible designer, builder and supervisor | Recognition and supervision by the Norwegian Authority for Building Quality |
| Sweden | Private controller | Certification and supervision by Swedish Accreditation Authority |

**Source:** Meijer and Visscher, 2016

Figure 3: Supervision of private controllers in European countries

New developments include the need for a broader and more effective quality assurance system within the building sector. Where rules and regulations related to quality and energy performance and also other essential elements, like safety, are very hard to evaluate throughout the whole building process, there's a need for clear and transparent responsibilities. As for in the Netherlands, developments are that these responsibilities will be regulated by the "Quality Assurance Act for construction". The Act is not yet implemented but will be in the near future. The main purpose for the proposed Act is to improve the quality of the construction projects and make the building practice itself responsible for the build quality. This corresponds with the goals of the INSITER-project. In this chapter we will give a brief review of the proposed "Quality Assurance Act for construction" and the possibilities to use the INSITER-methodology and tools in relation to the proposed act.

### 2.2.1 Dutch Quality Assurance Act for construction

The proposed new Dutch law for Quality Assurance Act for construction [1] (wet kwaliteitsborging voor het bouwen) consists of three main parts:

1. Change of the Housing Act (Woningwet)
2. Change of the Environmental Licensing Act (Wet Algemene Bepalingen Omgevingswet)
3. Change of the Dutch Civil Code (Burgelijk Wetboek)

The change in the Housing Act and the Environmental Licensing Act is a system change on how the local government controls the quality of the building. The control goes from public building control to private building control.

The change of the Civil Code is to improve the (legal) position of the customers. The contractor delivers an as-built dossier with all relevant information of the new building. The dossier consists at least of:

- The drawing, calculations of the building and the installations, the used materials and installations as the usage functions of the building;

- All the information necessary for the use and maintenance of the building.

The contractor is responsible for all deficits which are not discovered during the delivery of the building. This will mean a larger liability of the contractor compared to the current situation.

The main goals of the new Quality Assurance Act for construction are:
- strengthen those parties within building practice that do deliver high quality on construction projects;
- ensure that the building practice itself is explicitly responsible for the build quality;
- create incentives to increase quality in building.

### 2.2.2 How INSITER-methodology and tools can contribute to the Dutch Quality Act for construction?

***INSITER-methodology***

The eight step INSITER methodology will close the gap between the designed versus the as-built quality and energy performance of the new construction, refurbishment and maintenance projects. The correct working area with the right conditions, the right material in the right condition, the right place to install, use of BIM-based Augmented Reality to visualize, clashes and inconsistencies, BIM-based self-instruction and self-inspection and the BIM-based reporting the finished work.

The BIM-based information derived from the eight-step INSITER-methodology is already a strong base for the as-built dossier demanded by the proposed Quality Assurance Act for construction. The drawings, the used materials and installations and the way it has been installed and controlled give valuable input for the building dossier. The regulation for the building dossier demands information, but does not give recommendations about the standardisation and normalisation of this information. This has to be arranged in the building contract. For example: for building ventilation the national directive BRL8010 in the Netherlands gives a model report (example) of all the information which has to be supplied (visual, functional and measurements). The demanded information can be incorporated in the INSITER methodology.

The structured way of working with the INSITER-methodology will minimalize the performance gap and will reduce the risks for the contractor. The quality awareness of the workers on site is essential for reducing the gap between designed and as-built. The self-instruction (step 6) can be used to raise the awareness.

***Tools***

The INSITER software tools and hardware tools are used during the construction process to assist the workers on site and give feedback to the BIM-system. The hardware tools used in INSITER like laser, thermal and acoustic/ultrasound scans helps the worker on site to judge the quality of the work. This information is collected in the BIM-model. The software tool takes care that the information of the used material and tests are imported in the BIM-model.

## 2.3 Recommendations

Although the BIM-model is a very good tool to collect all the information about the building (for design, construction, use and demolition phase), not all stakeholders will or can use the BIM-model. Especially non-professional building owners will not be able to use the BIM-model. Software is needed to extract the right information for the building dossier out of the BIM-model.

A well-documented BIM-Model with all the information about the building can be used as a building dossier. But the information has to be kept updated. This makes the building dossier a dynamic document with the latest information.

# 3. Data interfaces between different equipment

In this chapter standardisation and normalisation related to data interfaces between different equipment are described

| International | European | National | Regional |
|---|---|---|---|
| | | | |

Inter-operability solutions between firmware/middleware and data interfaces of different types and makers of measurement and diagnostic equipment.

Involved methods for energy related self-inspection:

- avoid the presence of thermal bridges;
- ensure and control good air-tightness;
- measure U-values over large areas with non-contact solution;
- assess conformity to design during refurbishment.

## 3.1 Applied norms, standards and references

### 3.1.1 Thermal transmittance assessment

For the thermal transmittance assessment, the following standards are used:

- UNI EN ISO 6946 - Building components and building elements - Thermal resistance and thermal transmittance- Calculation method. May 2007.
- UNI EN ISO 8990 - Thermal insulation - Determination of steady-state thermal transmission properties - Calibrated and guarded hot box. 1999.
- ISO 9869-1 - Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance - Part 1: heat flow meter method. 2014.
- ISO 9869-2 - Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance - Part 2: Infrared method for wood frame dwelling 2018.
- UNI EN ISO 13786 - Thermal performance of building components - Dynamic thermal characteristics - Calculation methods. 2001.
- EN ISO 13791 - Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling - general criteria and validation procedures. 2012.
- EN ISO 13792 - Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling - Simplified methods. 2012.

Related to the thermal transmittance assessment, the following references are used:

- V. Tzifa, G. Papadakos, A. G. Papadopoulou, V. Marinakis & J. Psarras. Uncertainty and method limitations in a short-time measurement of the effective thermal transmittance on a building envelope using an infrared camera. s.l. : International Journal of Sustainable Energy , 2014.
- G. Pernigotto, A. Prada, F. Patuzzi, M. Baratieri and A. Gasparella. Characterization of the dynamic thermal

properties of the opaque. s.l. : 6th International Building Physics Conference, IBPC 2015, 2015.

- X. Meng, T. Luo, Y.Gao, L. Zhang, Q. Shen, E. Long. A new simple method to measure wall thermal transmittance in situ and its adaptability analysis, Applied Thermal Engineering 122 (2017) 747–757.
- M. Cucumo, A. De Rosa, V. Ferraro, D. Kaliakatsos, V. Marinelli. A method for the experimental evaluation in situ of the wall conductance, Energy and Buildings 38 (2006) 238–244.

### 3.1.2 Thermal bridges localization

For the thermal bridges localization, the following standards are used:

- UNI EN 13187 - Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method. 2000.
- UNI-EN ISO 14683 - Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values. 2007.
- UNI-EN ISO 10211-1 - Thermal bridges in building construction - Heat flows and surface temperatures - General calculation methods. 1998.
- BRE Information Paper IP 1/06, “Assessing the effects of thermal bridging at junctions and around openings”, 2006.

Related to the thermal transmittance assessment, the following references are used:

- F. Asdrubali, G. Baldinelli, F. Bianchi. A quantitative methodology to evaluate thermal bridges in buildings, Third International Conference on Applied Energy, Perugia, 2011.
- L. Zalewski, S. Lassue, D. Rousse, K. Boukhalfa. Experimental and numerical characterization of thermal bridges in prefabricated building walls, Energy Conversion and Management 51 (2010) 2869–2877.

### 3.1.3 3D laser scanning

Data Exchange Plans (DEPs) details what data the project will generate, and how will be processed, used and re-used. The following data formats are used:

- PTX: ASCII based interchange format for point cloud data. It utilizes the concept of separate scans, each with points defined in their own coordinate system and also a registration of all of those point clouds into a single coordinate system.
  Each point cloud starts with a header. Cyclone[1] sw exports PTX with 7 columns: (x, y, z, L, R, G, B). x, y, z are the point coordinates [in meters]; intensities (L[2]) use the decimal range [0, 1]; R (red), G (green), B (blue) have the integer range [0, 255].
- E57 The ASTM E57 Committee on 3D Imaging Systems has develop this format to meet the critical need in the 3D imaging industry for open standards that promote data interoperability among 3D imaging hardware and software systems.

[1] CARTIF uses a LEICA HDS-3000 laser scanner with associated Cyclone software.

[2] It refers to the luminance (luminous intensity per unit area at a given direction). As working with point clouds, the area is a dot, so it is understood as the luminous intensity in a given direction. Since this intensity is quantified with respect to the incident unit value, it really means the reflectivity of the target.

The E57 file format for 3D imaging data exchange is capable of storing point cloud data from laser scanners and other 3D imaging systems, as well as associated 2D imagery and core meta-data.

- XYZ An XYZ file is either an ASCII file or a binary file that contains a set of vertices and no other data unless an optional header is used.
- LAS Public file format for the interchange of LIDAR[3] data between vendors and customers. It is a binary file format that maintains information specific to the LIDAR nature of the data while not being overly complex. This represents an alternative used by many companies to proprietary systems or a generic ASCII file interchange system.

### 3.1.4 Sound measurements

The following international standards have been of use for the design and development of the acoustical analysis and inspection methodologies proposed in INSITER:

- ISO 16032:2004: Acoustics -- Measurement of sound pressure level from service equipment in buildings -- Engineering method
- ISO 9614-1:1993: Acoustics -- Determination of sound power levels of noise sources using sound intensity -- Part 1: Measurement at discrete points
- ISO 9614-2:1996: Acoustics -- Determination of sound power levels of noise sources using sound intensity -- Part 2: Measurement by scanning
- ISO 9614-3:2002: Acoustics -- Determination of sound power levels of noise sources using sound intensity -- Part 3: Precision method for measurement by scanning
- ISO 15186-1:2000: Acoustics -- Measurement of sound insulation in buildings and of building elements using sound intensity -- Part 1: Laboratory measurements
- ASTM E90 - 09: Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements
- ASTM E2249 - 02(2008): Standard Test Method for Laboratory Measurement of Airborne Transmission Loss of Building Partitions and Elements Using Sound Intensity

These standards determine conventional methodologies for acoustic inspection in controlled conditions. The methodologies proposed in INSITER act partly as a direct extension of these standards to the application to in-situ conditions. As a matter of fact, the INSITER methodology for sound transmission loss measurement is an extension of ISO-9614-2 (Acoustics -- Determination of sound power levels of noise sources using sound intensity -- Part 2: Measurement by scanning).

[3] The term LIDAR was actually created as a hybrid of "light" and "radar". It is popularly used as a technology to make high-resolution maps with applications in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics, airborne laser swath mapping (ALSM), laser altimetry, and contour mapping.

## 3.2 Opportunities for standardisation

### 3.2.1 Thermal measurements

IR thermograph will be exploited for the U-Value distribution assessment and thermal bridges localisation during the building process. For this purpose an excitation procedure will be designed to produce controlled thermal gradients between the wall surfaces and induce a thermal heat transfer across the wall. The results of the sub-task will be a standardised procedure and prototyping using different commercial IR systems that allow storing thermal data in open formats as ".txt" which can be post-processed with the aim to extrapolate the required thermal aspect (U-value, thermal bridge).

The added value of the procedures developed within INSITER with respect to the state-of the-art can be summarised as following:

- concerning the U-value assessment, the heat transfer measurement across the building element has been coupled with a numerical/analytical calculation with the aim to increase the thermal data and improve the statistical representativeness of the sample processed, in order to reduce the convergence time in U-value estimation,
- concerning the thermal bridge localisation a threshold-based image processing procedure has been proposed that allows superimposing on the building element photograph the pixels affected by thermal bridges.

The procedures have been described in details in previous deliverables focused on the procedure (D1.5), measurement techniques (D2.3) and applications (D5.2, for laboratory testing, D5.5, for real demo cases) description.

### 3.2.2 Sound measurements

The number of formats in which measurement data is expressed tends to grow and evolve according to specific (and often conflicting) needs in terms of completeness, readability, portability, redundancy, etc. As proprietary file formats are developed, for instance in the private sector, software interoperability based solely on file input/output is at risk. The case of the present project is a good example where file formats have been discussed and agreed upon.

In the specific case of acoustical experimental methodologies, a post-processing procedure has been established in order to convert measurement data from a proprietary Microsoft format to raw measurement data and then into three-dimensional models containing the spatial location, orientation and magnitude of acoustic data (sound intensity vector fields and sound pressure maps). The choice of a 2-step conversion procedure is motivated by the ease of use of existing software, for instance for the SoundBrush sound intensity probe, for prototyping purposes. However, in the future, steps must be taken in order to directly interface the developed tools.

Ideally, a standard format such as the AES Standard on the Spatially Oriented Format for Acoustics (SOFA) could be seen as an example, AES69-2015: AES standard for file exchange - Spatial acoustic data file format. Such a standardised file format makes it possible to assign spatial attributes to acoustical data.

## 3.3 Barriers found during INSITER

### 3.3.1 Thermal measurements

The main barriers to the application of the INSITER methodologies are related to the commercial systems available in the market and to their applicability on-site during building construction.

As already stated in the previous section the proposed procedures are based on a post processing of the measurement data that are possible only if the thermal signals can be stored and exported from the IR system as numeric value in ".txt" or ".ascii" format.

The applicability on-site of the procedure is strongly limited by the environmental conditions during the measurement. Amongst several limitations that have been detailed in the practical recommendation for in-situ applicability (see D5.2) the main requirement to be respected is that a sufficient gradient between internal and external building elements surface temperature exists. Actual standards require that such thermal gradient must be above 10 °C. This condition must be met also for the INSITER procedure, but is almost impossible when the building envelope is under construction because the building is not conditioned and indoor and outdoor temperature is almost coincident. In order to fulfil the thermal gradient requirement it has been proposed to apply an artificial thermal load to the building element under test that would assure a temperature gradient between element surfaces and would add a second benefice, i.e. it would reduce the testing time if the thermal load cycle period is reduced according to the building element phase shift.

### 3.3.2 3D laser scanning

The barriers found during INSITER: the barriers that involve the interconnection of 2D information with 3D laser scanning are directly related to making it accessible into BIM. This is being overcome by using the INSITER-DLL, widely described and updated in D2.3, D5.2, D5.3, D5.4 and finished on the on-going D2.4.
An "INSITER impact paper" published in February 2018 about interoperability for self-inspection in buildings, which can be pointed out in the D6.2 References. CARTIF, RDF, DEMO and HVC made this paper. Please take into account specially the Section 3: Interoperability Standards for Data Exchange in Buildings and Section 5: Data Integration Mechanisms. This latter section try to solve the barrier found in INSITER on 2D/3D interconnection and BIM.

### 3.3.3 Sound measurements

The main barrier encountered during the project in this respect was as a matter of fact the unavailability of a format assigning 3D attributes to acoustic measurement data. The interface that was developed acts as a conversion tool. The latter should be incorporated in a dedicated software application, as suggested in D5.7 as part of actions to take to increment the technology readiness level.

# 4. BIM open-interoperability related

In this chapter standardisation and normalisation related to the building quality control and certification are addressed

| International | European | National | Regional |
|---|---|---|---|
| | | | |
| Open standardisation for BIM (data inter-operability). Experts within INSITER consortium partners are involved in BuildingSMART platform. | | | |

One of the challenges to carry out self-inspection is the lack of interoperability between the various equipment used. Devices and current tools deployed on-site do not speak the same language, which leads to a lack of communication. Therefore, INSITER presents a framework under which the equipment is able to send information in a common format. First, the Industry Foundation Classes (IFC) de-facto standard is a viable data model to represent all the information related to the building project. Along these lines, Building Information Modelling (BIM) information and IFC-compliant databases have been designed for the representation of data coming from Computer-Aided Design (CAD) modelling, laser scanning, thermography and sensor networks. Besides the IFC-data repositories, the framework is a multi-layer architecture with the goal of ensuring interoperability and promoting the stakeholders' objectives for self-inspection during the entire construction process.

## 4.1 Applied norms, standards and references

Within the world of Information Technologies (IT), there is an ever-growing number of information exchange standards, each with its own purpose and scope. The INSITER project selected standards take into account the possibility that existing standard(s) may not fulfil the needs and requirements, and could possibly require the combination of several standards. For INSITER purposes, the standard IFC was the most relevant candidate for INSITER selection. But although IFC is very complete, the INSITER framework is still required to offer support for multiple file formats, as well as dedicated semantic structures. Within INSITER the three most frequently used versions of this IFC standard are supported:

- IFC2x3 TC1, although already developed 10 years ago, this is the most recent version of the IFC2x series and by far the most used version of IFC during the INSITER project.
- IFC4, this version has many improvements over the IFC2x3 TC1 standard and is the preferred standard for the years to come. Although this standard also exists already from before the start of INSITER, it is still not adopted and widely available as IFC2x3 TC1. During the INSITER project IFC4 was replaced by IFC4 ADD1 and IFC4 ADD2. Within the INSITER tools we will support both IFC4 and IFC4 ADD2 as the modelling tools we used in WP4 are generating IFC4 files for both versions.
- IFC4x1, this version has several important improvements over IFC4, especially the integrated Alignment extension allows support for GIS content. Within INSITER we support IFC4x1 FINAL. Note, very recently BuildingSMART released a version IFC4x1 TC1, we did not apply exhaustive tests to see if this influences the tools created,

however it is expected this version will work automatically given that the changes between IFC4x1 FINAL and IFC4x1 TC1 are in areas that should not affect the INSITER tools.

For self-instruction content dynamic / parametric geometry is modelled and used to be visualized on PC's and mobile devices. This parametric content has been modelled against open standard CMO with Extensions as developed in other EU projects, for the geometrical part specifically the EU Framework Program project Proficient.

In order to calculate cost based on BIM models, more specifically based on above named IFC standards the most important input from BIM can be divided in two sources:

- The classification of elements, i.e. not only the entities as available in the different IFC standards but also the further detailed definitions of the different elements.
- The quantities that are derived from the geometrical representations.

The classification within IFC is already quite detailed and many projects also within BuildingSMART like bSDD (BuildingSMART Data-Dictionary) are working on further improving this classification. However the quantities is often a complex area, CAD systems themselves of course know or can derive quantities from the geometry that defines the elements. However, the uniformity and the process of sending this quantity information through the IFC path is often application dependent or sometimes not available at all.

Within INSITER a formalized way of defining QTO (Quantity Take-Off) is developed, tooling to generate such QTO values based on any of the available IFC standards is developed and made available.

To enable integration of measurement results within BIM in a user friendly way probably the most natural way is to attach created images created by the measurement devices onto the geometrical representations from the elements within BIM. This can perfectly be done making use of textures, something we see often well supported in representation formats like Collada. All supported IFC versions have basic support for textures, however the IFC2x3 TC1 standard has some critical flaws in its definition preventing correct creation of textures. Therefore within INSITER a tool is created to attach textures towards files created according to the IFC4 (ADD2) and IFC4x1 FINAL schemas. Although this is not adding new knowledge for the standardisation body, it is the first publicly available tool that is able to create IFC files with embedded textures. This innovation is directly also causing the issue that there is only 1 application (out of 100+ that support IFC4) that visualizes actually such content. Within INSITER we made a second viewer as well as support for online viewing of such content.

## 4.2 Opportunities for standardisation

### 4.2.1 IFC Open standard

For projects like INSITER, and within the building and construction industry, the choice regarding exchange standards is straightforward. There is only one open standard (IFC, also called ISO16739) that is widely accepted, mature and covers most of the disciplines within the sector [5][6]. Within INSITER, the extensions added to the later versions of IFC fit very well for the purpose of the framework. Unfortunately, embedding the newer versions of the open IFC standard is progressing slowly, and current software often has utilized the older, but successful, IFC2x3 TC1 version, rather than IFC4 (ADD1/2) or IFC4x1. Therefore, INSITER will help the implementers of the open standard in pushing these great new functionalities. Currently, a population of existing IFC4 files, with one or more different embedded textures, can be used as working examples to assist software companies with populated data which has not yet been explored.

The development within INSITER contains relevant results for the used open standards also.

### 4.2.2 Opportunities for IFC

On the applications side (most probably) the first public application able to adjust IFC4 / IFC4x1 files by integrating textures can help a wider and quicker adaption of texture information in IFC files. Currently a major drawback of IFC in case of visualization is the absence of texture information, for this reason in many situations open standards like Collada are preferred over IFC even though such alternatives are missing a lot of semantics in their representation. The INSITER solution is an important step in tackling this drawback.

One other major issue within IFC is that it is single file based and integration of several IFC models can be done only if the used application supports such functionality. Within INSITER the IFC merging application allows several IFC files to be merged into 1, this then allows any application able to load a single IFC file to show combined / merged IFC content. A similar benefit can be found in the created IFC clipping application.

On the standardisation side the within INSITER developed QTO standard can help defining an application independent solution to retrieve quantities. The quantities are directly defined on top of available geometry, they could give valuable feedback in itself, however in case quantity information is available in the file already it can act as validation data.

## 4.3 Barriers found during INSITER

As INSITER strongly relies on open standards and use existing commercial applications like Revit to develop content, INSITER is depending on the quality and functionality of these commercial applications. One important barrier found was that the adaption of open standards is applied slowly. For many demonstration cases using an 10 year old open standard was more convenient than using its 5 year younger follow-up, not because the more modern version of the standard was not better, but just because of support within the applications to be used.

Two important other limitations were the absence of ability to integrate images (technically called textures) and the single file based setup. Both were partially solved by created INSITER tools that can enrich the files via a dedicated enrichment tool.

However, the concept of BIM is applied and understood in many ways (e.g. a simple information repository, a complete data model, etc.). In the design, construction and maintenance phases, there is no single BIM model that is used the same way, by all the stakeholders. This also applies for self-instruction, and therefore BIM application needs to be adjusted for the self-instruction process. In practice, common BIM models are too complicated for this purpose; there is a plethora of information which is not structured in a step-by-step process for on-site construction workers. It is difficult to inspect details and technical quality by comparing the BIM model and the realized building. The data for comparison with the BIM models is acquired via three-dimensional (3D) measurement devices adjusted for self-inspection. In practice, there are issues with robustness, and user-friendliness, as well as time and cost effectiveness for applying high-tech 3D laser scanning, thermal imaging and acoustic measurement, during on-site working processes. Aside from the aforementioned difficulties, other challenges also arise in the form of differences in geolocations, building typologies and materials, working cultures, methodologies, software tools and data registration. The main challenge in developing a toolset to support the self-inspection process is the implementation of the appropriate interoperability standards for data exchange in buildings. Industry Foundation Classes (IFC), an open industry standard format, has come into play for this purpose. Under the INSITER approach, based on the IFC standard [6], the various necessary data and information can be merged to provide useful data; the combination of all these resources improves the construction process by reducing the costs and time, while concurrently and pre-emptively detecting potential errors.[4]

# 5. Procurement related

In this chapter standardisation and normalisation related to procurement is addressed

<table>
<tr><th>International</th><th>European</th><th>National</th><th>Regional</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Experts within INSITER consortium partners are involved in standardisation of BIM use for procurement.<br><br>Increased correlation between building's Quality and Performance, and Economic Value for a higher potential exploitation on the existing building stock, with huge business development impact. This serves as the basis for new Performance Based Contract (PBC), and Energy and Maintenance Services. INSITER will release the efficacy of procurement and delivery strategies / mechanisms (PFI, DBFMO etc.) in delivering project objectives and quality outcomes.</td></tr>
</table>

## 5.1 Applied norms, standards and references

Within INSITER no research is done that covers or used procurement related norms or standards. In a broader view though, there are some interesting standards to include to the project. The most important is ISO 10845. This standard consists of multiple parts, as followed:

- ISO 10845 under the general title Construction procurement and with the following most relevant sub-parts:
  - Part 1: Processes, methods and procedures
  - Part 2: Formatting and compilation of procurement documentation
  - Part 3: Standard conditions of tender

Construction procurement involves not only engineering and construction works contracts, but also supply contracts that involve the purchase of construction materials and equipment, services relating to any aspect of construction including professional services, disposals of surplus materials and equipment and disposals in the form of demolitions.[11] So, important for the use in INSITER is the procedure of establishing what is to be procured. Not only the construction of the building, but far more interesting are the requirements related to planning, execution, inspection and evaluation.

## 5.2 Opportunities for standardisation

There is a finite range of methods and procedures associated with a procurement process which can be standardised around a set of construction objectives (cost, time and quality). Public, private, international organizations and main contractors can establish their procurement systems around these standard procedures and methods. Contractors who contract with such organizations can in turn be required to apply relevant standard procedures and methods when procuring subcontracting construction works associated with their contracts. For INSITER, for instance, a contractor can be required to apply a standard procedure for testing (scope and test-protocols), transportation and delivering of a specific prefab façade element.

Where these procedures related to the construction objectives are generic, standardisation may be useful. Another example is INSITER's cost and time management. The requirement to apply an INSITER-like methodology for cost and time management could be the new standard, if the methodology in practice may prove to be successful.

### 5.2.1 Self-inspection at procurement

The Chartered Institute of Procurement and Supply (CIPS) promotes a model of "five rights" which it claims are "a traditional formula expressing the basic objectives of procurement and the general criteria by which procurement performance is measured", namely that goods and services purchased should be of the right quality, in the right quantity, delivered to the right place at the right time and obtained at the right price.[8] All of these aspects have an important role in INSITER's methodology. Within these objectives, there a need for high-quality, reliable products and manufacturers recognize that they need to implement quality systems to assure this high quality. A process of self-inspection is an important factor in contributing to this quality system and it is necessary to develop logical risk based systems around self-inspection, to rate, qualify and reward the manufacturing facilities.

One way is to encouraged manufacturers to enhance supply chain transparency by taking full responsibility of inline and pre-shipment inspection to improve product quality and delivery. The process must have a focus on:

1. Risk Assessments
2. Inspection Process Validation, and
3. Training and Qualification of People and Process

### 5.2.2 Performance-based contracting (PBC)

Performance based contracting (PBC) in the construction sector is a product support strategy used to achieve measurable performance of the building. A PBC approach focuses on developing strategic performance metrics and directly relating contracting payment to performance against these metrics. Common metrics include availability, reliability, maintainability, supportability and total cost of ownership. The primary means of accomplishing this are through incentivized, long-term contracts with specific and measurable levels of operational performance defined by the customer and agreed on by contracting parties. In the energy sector, PBC is used to establish a contract that aims to reduce energy consumption. These projects are procured using the same idea as PBC but in this specific case it is known as Energy Performance Contracting (EPC)[4].

In certain cases, the value of applying the INSITER methodology could be the contribution to realize what was aimed. Energy Performance Contracts are complex and extensive and, more than with normal contracting, the final performance and quality of the refurbished building is a critical factor for the contractor.

[4] Energy Performance Contracting (EPC) is a form of 'creative financing' for capital improvement which allows funding energy upgrades from cost reductions. Under an EPC arrangement an external organisation (ESCO – Energy Service Company) implements a project to deliver energy efficiency, or a renewable energy project, and uses the stream of income from the cost savings, or the renewable energy produced, to repay the costs of the project, including the costs of the investment. Essentially the ESCO will not receive its payment unless the project delivers energy savings as expected.

## 5.3 Barriers found during INSITER

During INSITER research there hasn't been focus on procurement related issues. Some barriers that might occur in procurement of projects are the embedment of INSITER like quality assurance systems. Because of the comprehensiveness of INSITER and many dependency factors during construction to succeed in its mission (for example the profound inspections and all-encompassing training), the procurement itself may be the barrier for implementation of the methodology.

# 6. Guidelines related

In this chapter, the standardisation related to generic guidelines of 'construction errors and common building defects' are addressed.

| International | European | National | Regional |
| --- | --- | --- | --- |
| | ■ | ■ | |
| Generic guidelines of 'construction errors and common building defects', which will be actualised and extended in INSITER based on the Dutch technical norm NEN2726 as well as the standardisation results from the EU project BRITE EURAM on Condition Assessment and Maintenance Strategies for Buildings and Building Components. | | | |

## 6.1 Applied norms, standards and references

The following national and international standards have been of use for the development of the generic guidelines of 'construction errors and common building defects' for INSITER methodology:

- NEN 2767-2:2008 - Condition assessment of building and installation components;
- Brite Euram 4213 - Condition Assessment And Maintenance Strategies For Buildings And Building Components;
- UNI 10721 - Technical control surveyor service for buildings and civil engineering.

The Dutch "NEN 2767 Condition assessment" for building and MEP/HVAC and the Italian the "UNI 10721 - Technical control surveyor service for buildings and civil engineering" both aim at objectively assessing technical quality of building. Condition assessment only has a focus on component conditions and not the functional embedment in the greater system and entire building. INSITER's methodology has been developed to cover the full aspect of performance based evaluation and quality assurance.

## 6.2 Opportunities for standardisation

The guidelines consist of a procedure with structural approach to plan, execute, inspect and evaluate the construction process, defined within 8-steps. All steps have an added value to the full methodology and cannot be seen as solitary elements of the entire method. The guidelines are the embedment of INSITER methodology and are not a viable option for standardisation.

### 6.2.1 Standardisation of quality improvement

The structural elements of planning, execution, inspection and evaluation, however, are easily fitted into the well-known PDCA (plan–do–check–act) method for the control and continuous improvement of processes.[8] Another version of this PDCA cycle is OPDCA. The added "O" stands for observation or to "Observe the current condition".[10]

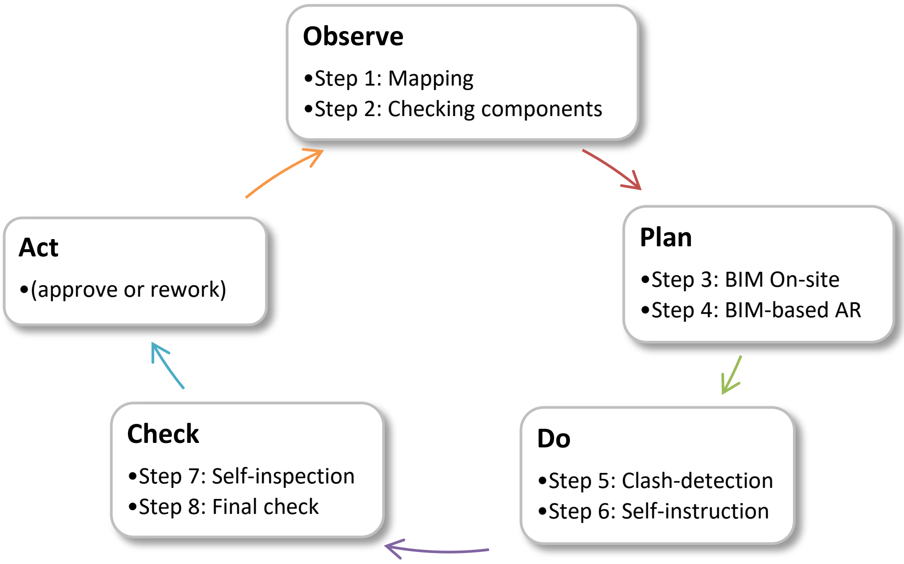



Figure 4: The INSITER methodology in the well-known (O)PDCA method

This procedure of improving building quality by a structural approach can be seen in a more widely accepted and applicable explanation:

1. **Observe**: This phase involves assessing the current situation; construction site, existing building, the work environment of construction workers, and also assessment (inspection) of the delivered components.
   - Step 1: Mapping
   - Step 2: Checking components
2. **Plan**: The planning phase involves figuring out how the ongoing process can be improved and knowing what types of instruments are therefore needed. Establishing the scope and objectives (KPIs) of the upcoming work.
   - Step 3: BIM On-site
   - Step 4: BIM-based AR
3. **Do**: The do phase allows the plan from the previous step to be enacted. For construction work this consists of the preparation and mounting of components and elements.
   - Step 5: Clash detection
   - Step 6: Self-instruction
4. **Check**: During the check phase, the executed work is evaluated. This is supported by inspection protocols and measurement procedures. Results are weighted against the acceptable tolerances.
   - Step 7: Self-inspection
   - Step 8: Final check
5. **Act**: If the check phase shows that the executed work is as planned, than the work can be approved. But if not, action is needed to redo the work and improve the process or system.

- Not a part of INSITER

6. **Adjust**: There can also be included a second ‘a’ to the method. Meaning that when the construction process is finished and all improvements are made, the adjust phase will be the continuation of the act phase. The adjust phase allows the process to be monitored after the changes have been implemented and fix them accordingly. This makes the (O)PDCA cycle a continuous improvement method, even after building delivery.
   - Not a part of INSITER

The proposal for standardised approach would be the continuous consolidation of small and large scale construction processes through the (O)PDCA approach. There must be a prominent role for observation, (self-)instruction, (self-)inspection and quick and smart decision making throughout the construction processes. The figure below demonstrates the continuous improvement with the aim to be ‘on top of the mountain’ at the time of building delivery.

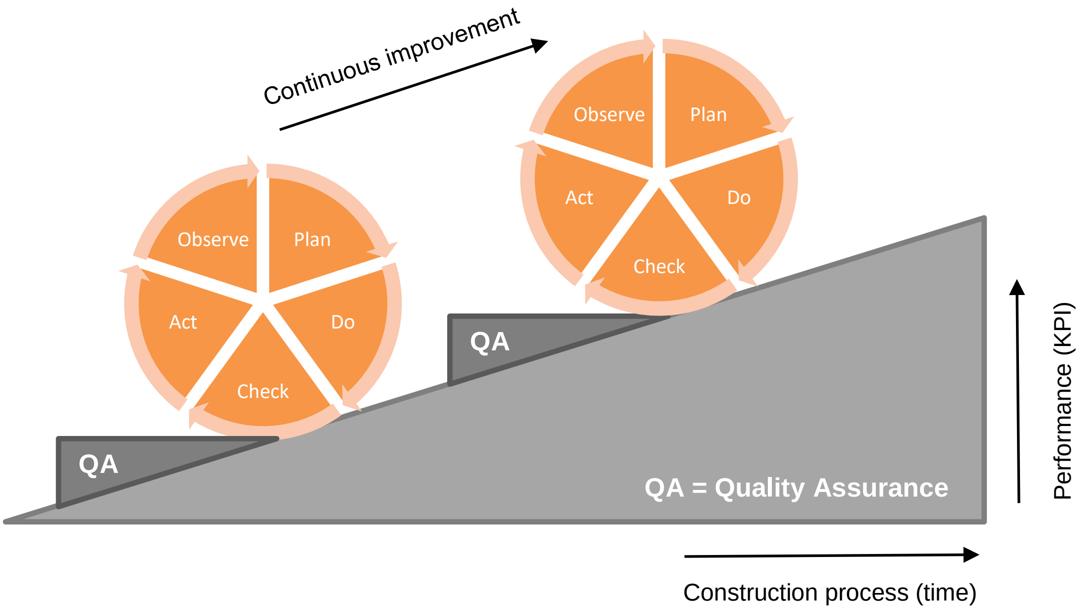



Figure 5: Consolidation through standardisation of (O)PDCA in construction

#### 6.2.2 Standardisation of self-inspection protocols

In INSITER, self-inspection protocols are checks on the quality of the construction or installation of component. We distinguish 4 types of errors:

1. Wrong (type/dimension) of components
2. Components are damaged
3. Wrong mounting/assembling of components
4. Components are incorrectly adjusted or set

Self-inspection protocols contribute to drastically reduce or eliminate these errors. Therefore the protocols must be

thoroughly selected and (in most cases) be tailor-made for each project.
There is a need, though, for standardisation of inspection protocols. Besides the product-related inspections, there's a wide range of generic inspection protocols that can apply to a certain component. For example the correct placement of a vacuum siphon on an air handling unit with cooling section. Branch organizations could take the lead to build these generic protocols and embed them in the construction processes of their manufacturers markets.

To be able to use protocols, they must consist of three aspects:

- What (is being inspected/checked)? For example 'checking the sealing of two façade elements'.
- When (the inspection is performed)? For example 'after adjusting the façade elements'.
- Who (is performing the inspection)? For example 'the construction worker who has adjusted the elements'.

All other information, like how the inspection is done, is complementary.

## 6.3 Barriers found during INSITER

There were no barriers considering the process of the guidelines. The challenges lie in the fact that all steps of the methodology must work together to support the continuous improvement process. Because of the complexity of construction, the strict timelines and cost aspects, the large amount of actor and the complicated interaction between the KPIs, the key to success will lie in the thoroughness of the preparation. Therefore, all steps must be carefully prepared before construction starts, including the right training for all actors involved.

# References


[1] Changed proposal Quality Assurance Act sent to the Senate February 21st 2017, https://www.eerstekamer.nl/behandeling/20170221/gewijzigd_voorstel_van_wet/document3/f=/vkbyg97mz1x9.pdf

[2] Frits Meijer, Henk Visscher, (2017) "Quality control of constructions: European trends and developments", International Journal of Law in the Built Environment, Vol. 9 Issue: 2, pp.143-161, https://doi.org/10.1108/IJLBE-02-2017-0003

[3] S.L. (Lieke) Nieman (2017) " The Quality Assurance act for construction in the building process" The consequences of the new Quality Assurance Act for the building process in relation to SE and BIM

[4] José L. Hernández, Pedro Martín Lerones,Peter Bonsma, Andrè van Delft, Richard Deighton and Jan-Derrick Braun, (2018) "An IFC Interoperability Framework for Self-Inspection Process in Buildings", INSITER consortium, EU.

[5] IFC Overview. Available online: http://www.buildingsmart-tech.org/specifications/ifc-overview

[6] IFC4 Release. Available online: http://www.buildingsmart-tech.org/specifications/ifc-releases/ifc4-release

[7] CIPS in partnership with Profex Publishing, Procurement and Supply Operations, 2012, revised 2016, pp. 1-2

[8] CIPS, Procurement Glossary - F Archived 14 April 2017 at the Wayback Machine., accessed 14 March 2017

[9] Tague, Nancy R. (2005) [1995]. "Plan–Do–Study–Act cycle". The quality toolbox (2nd ed.). Milwaukee: ASQ Quality Press. pp. 390–392. ISBN 0873896394. OCLC 57251077. Retrieved 2017-10-21.

[10] Foresight University, The Foresight Guide, Shewhart's Learning and Deming's Quality Cycle

[11] Will Hughes & Samuel Laryea (2009), "Standardisation of procurement: National or International?", University of Reading, Reading, UK