D6.1 Training modules and pilot training courses ANNEX 4

INSITER Implementation training Syllabus

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Annex 4 - INSITER Implementation training Syllabus

Content

1 INSITER

1.1 Introduction

Buildings need to be designed and built ever more energy-efficient.

The sustainable future of the building environment is accompanied by improved construction architectural detailing and new techniques. Consider, for example, a heat pump or prefabricated wall parts that have to be connected airtight. If the contractor cannot apply the innovations properly, the intended sustainability will not be accomplished. The customer does not get what he requested and the contractor risks failure costs and a dissatisfied customer.

The contractor who realizes the building will be increasingly responsible for the final quality and energy efficiency of the building. This quality must not only be improved, but also guaranteed.

Quality assurance helps the contractor to build better. By identifying the risks in advance and by defining the required quality checks during project preparation, errors or deviations during construction can be prevented. This improves the quality of the final building and ensures that the intended 'sustainability' is also realized.

Quality assurance can be improved by using INSITER.

Figure 1 Illustration of INSITER at the constructio site

1.2 What is INSITER?

INSITER is a European research project wich developed Intuitive Self-Inspection Techniques using Augmented Reality for construction, refurbishment and maintenance of **energy-efficient buildings (EEB)** made of **prefabricated components.**

The main question for INSITER is: How can quality assurance be efficiently organized, in such a way that:

1. quality increases;
2. failure costs are being reduced, and;
3. realization costs remain within the limits?

Hypothesis of execution during construction:

1. The benefits from using energy-efficient building components are lost due to lack of knowledge or information, resulting in incorrect fitting during the construction process. This affects the final performance of the building.

2. The construction sector is characterised by a segmented approach involving a variety of skills and expertise with different roles and responsibilities. During construction, each (sub-) contractor must ensure that its contribution fits into the overall quality framework, defined collectively at the design level.

INSITER aims to eliminate the gaps in quality and energy performance between design and realisation of energy-efficient buildings based on prefabricated components.

By bringing self-instruction and self-inspection to the worker on site/ craftsmen, INSITER will improve the quality and energy efficiency of the building.

Self-instruction and self-inspection are part of the in INSITER developed 8-step methodology.

To explain the INSITER 8-step methodology a training with a PPT presentation has been developed.

This syllabus contains a lot of information for people who are more interested in INSITER and the 8-step methodology.

This syllabus leads you, in addition to the PPT, through the developed 8-step methodology.

It tells you what the step means, who is/can be involved, what qualifications you need, etc.

In INSITER the critical components and construction errors which have the most influence on the energy performance of energy-efficient buildings based on prefabricated components are examined. The critical components have special attention in the 8-step methodology.

1.3 Critical components and construction errors

Building systems are divided into levels of the construction or into individual components such as roof, facades etc. or, from another perspective, according to work packages of the trades involved in the construction. The classification of building elements is an integral and key component of some national standards. Elements are defined as major components that are common to most buildings.

Dealing with Energy-efficient Buildings (EeB) or Intelligent buildings means namely to clearly identify:

1) the constituent elements of the buildings and

2) the mutual interactions between them, in each stage of the design and construction process.

Therefore, for these buildings, a classification based on the function of an element, is the most suitable. Elements usually perform a given function, regardless of the design specification, construction method, or materials used, as follows:

- Building envelope;
- Interior systems;
- Load bearing elements;
- MEP-HVAC.

All these different functions shall be strictly related within the prefab context: in general, the term prefabrication can apply to any construction method where a significant part of the construction takes place off-site in a factory that produces relatively large, complex pieces that are then assembled at the site into the finished building. Because the interior systems and load bearing elements do not effect the energy efficiency and (to lesser extend) environmental quality, the EeB is divided only in the 'building envelope' and 'MEP-HVAC'.

1.3.1 Building envelope

The building envelope – the parts of a building that form the primary thermal barrier between interior and exterior – plays a key role in determining levels of comfort, natural lighting and ventilation, and how much energy is required to heat and cool a building. The building envelope impact on energy consumption should not be underestimated: globally, space heating and cooling account for over one-third of all energy consumed in buildings, rising to as much as 50% in cold climates and over 60% in the residential sub-sector in cold climate countries. The envelope design and construction also affects the comfort and productivity of occupants.

Following the workflow of the construction process, all elements of the building envelope that affect energy use have been identified, and the classification has been made as follows (see also Figure 2):

1. **Foundation and ground floor**, including foundation connection and façade connection. The ground floor elements including their foundations are considered as a specific sub-system because of the constant contact with the soil and corresponding risks of performance loss.

2. **Solid prefab façades**, including window openings (façade – frame). The vertical elements mainly present problems of connection with the background building structure and with the connection between different modules.

3. **Glass façades (curtain walls)**. These kinds of components present similar issues to solid façades in terms of air tightness and general performance (from acoustic, thermal points of view). In addition, they present specific problems related to the presence of glass panes and sealings.

4. **Roofing systems**. These elements can be flat or inclined. Flat roofs are vulnerable for accumulation of water whereas the inclined roofs have to deal with run-off water. Roofs are critical in terms of energy savings especially regarding heat loss and waterproofing. The performance analysis of the roof elements also includes their connection to the vertical façade elements.

5. **Connections between existing building and new elements**. Refurbishment processes have been identified as involving envelope configurations: in this perspective, an additional section has been included in the deliverable, mainly focusing on the connection between new and existing.

1. Foundation and ground floor

2. Building envelope: Exterior walls

3. Building envelope: Glass facades (curtain walls)

4. Building envelope: Roof systems

5. Connection between new and existing

Figure 2 Subdivision of building systems

1.3.2 MEP-HVAC

HVAC stands for Heating, Ventilation, and Air Conditioning systems, while MEP (Mechanical, Electrical & Plumbing) covers the whole range of building services. Building services are the systems, installed in buildings that make them comfortable, functional, efficient, and safe. MEP systems are generally not part of the constructional elements of a building, but do interfere with the building envelope. Also, MEP components like piping and ducts can be integrated in (prefab) building elements. Within INSITER we focus on the installations that influence the indoor environmental quality and/or energy efficiency.

Because not all building services have a large impact on the energy efficiency or environmental quality, or have any impact at all, not all installations are included. Figure 3 shows the energy consumption in residential and commercial buildings. Both pie charts make clear that space heating is the largest energy consumer. In residential buildings water heating is also a major consumer, while lighting is of less importance. In commercial buildings, however, lighting is still of reasonable importance. The 'Other (16%)' part of commercial buildings is primarily made up by (ICT) appliances.

Figure 3 EU Building energy consumption for residential and commercial buildings

For indoor environmental quality, the comfort factors are influenced by multiple disciplines. For example, thermal comfort depends on the heating and cooling system of a building. But it is also influenced by the building envelope. If there is leakage of cold outside air through connections to building elements to each other or lead-through, discomfort can occur due to draught.

The following environmental quality issues are influenced by:

- **Thermal comfort**: Building envelope (thermal insulation, airtightness), heating, cooling, ventilation systems.
- **Visual comfort**: Building envelope (windows), lighting systems.
- **Acoustic comfort**: Building envelope (acoustic insulation), large HVAC components, and appliances.
- **Indoor air quality**: Ventilation system, appliances (pollution).

Because appliances are not a part of the building design, the main MEP-HVAC critical components are

- **Heating & cooling** (put together, because of their strong interrelationship);
- **Ventilation**;
- **Hot water**;
- **Lighting**.

1.3.3 Most frequent construction errors

If 20% of all construction errors effect 80% of the total effect of all errors on the energy efficiency and environmental quality, then the focus should be on these errors. For that reason, the selection of the most frequent (or common) construction errors has been done by selecting a shortlist. This shortlist contains a group of currently existing construction process errors. They have been evaluated following the regular timeline for projects from design to prefab, mounting on site and maintenance. The shortlisted construction errors are:

1. Phase 0 not appropriately worked out: Especially the programming of projects setting the boundaries in terms of costs, time and quality with the clients are done insufficiently and the total quality is under-defined, often the experts/the personnel chosen are not fitting to the project demands, this is even more crucial in terms of renovation projects as the analysis of the existing building and the design for the renovation have to be in line, structural reliability assessment is not done the right way, too.

2. BIM clash detection not applied/bad applied in terms of underdeveloped BIM model: No aggregated holistic and consistent data model with design and engineering details available, as a result the components might be badly prefabricated.

3. Dimensional accuracy of the prefab components is not used as a benchmark in the design, built as designed and mounted on site overlay data model, joints are not matching with the needs of the tolerances and there are design and technical defects.

4. Assembly –virtual pre-assembly at the factory- is not done causing lot of time cost and quality problems on site. The logistics of prefab components might cause unforeseen damages and there is no benchmark for the use or withdraw of these elements.

5. Air leakage problems created by wrong/not appropriate sealing of doors/windows, component to component connection or component to other bearing (existing in renovation sector) structure or envelope building components.

6. The pre-assembly of the MEP/HVAC components is done in a wrong way, the plug and play connections on site are not working, missing quality check of components that are built in causing lot of demand for rectifying these defects.

7. Not appropriate commissioning especially of the MEP/HVAC system and its components, no user behaviour oriented steering opportunity of the system, no continuous monitoring in order to have an ongoing calibration.

8. Bad qualification of mounting workers on site causes eg. wrong positioning of prefab elements, no appropriate inspection after the construction work has been done.

This shortlist can be divided into the following categories:
- The component is damaged or polluted (during transportation or storage, or after mounting);
- The wrong component is installed/mounted (or installed/mounted in the wrong place);
- The component is installed/mounted incorrectly (bad connection, wrong fastening/sealing materials);
- The component is provided with the wrong settings (mainly related to building control).

It is recognized that not all errors are covered during research. From lessons learned, the list of errors can (and will) infinitely be extended. Because of the catogerization, INSITER will always be able to prevent possible errors.

2 Training 8-step methodology

Within INSITER, a new "8-step" methodology for new construction and refurbishment of **energy-efficient buildings (EEB)** made of **prefabricated components** has been developed.

The INSITER project aims to increase building quality and optimizes energy performance in buildings. This optimisation is achieved by eliminating the gaps between design and realisation based on prefabricated components. The final INSITER solution includes:

- a new self-instruction process;
- a new self-inspection process;
- both processes supported by intuitive and cost-effective tools (Augmented Reality); and
- all connected through the BIM process and empowered by simulation and monitoring software.

In the first part of the training, the 8-step methodology will be explained. At the end of this part a new simulation based inspection will be introduced. In the third part of the training, a practical case will be discussed. The training ends with a summary of the benefits of the 8-step methodology.

Figure 4 Illustration of a building based on prefab components

Figure 5 Illustration of working on a prefab building element

Figure 6 Illustration partly prefab HVAC/ MEP components

2.1 Introduction INSITER collaboration platform

INSITER works with a digital collaboration platform for the 8-step methodology. In the next image this is visualised.

Figure 7 INSITER digital collaboration platform

In INSITER inspection data (output from measurement tools) stored in images is combined with positioning data and stored in the BIM-model.

Figure 8 RE Guidelines app

2.2 INSITER Guidelines

To instruct workers on-site, the Guidelines app has been developed In the INSITER project.

The INSITER 8-step methodology aims at detecting and preventing quality and performance gaps between the design and the realization of buildings made of prefab components. This aim is to be achieved by the Self-Instruction and Self-Inspection methods, supported by BIM-based software tools, Augmented Reality, and 3D measurement instruments.

In this context, the "INSITER Guidelines" are practical guiding principles for applying the developed within INSITER self-instruction and self-inspection methods, measurement procedures and tools in order to meet INSITER's goal. In other words, the "INSITER Guidelines" is the synthesis of the knowledge from INSITER, and the bridge to bring research knowledge into practical implementation.

Figure 9 The RE Guidelines app provides guidance to the worker on-site

A digital format is selected for the implementation of the "INSITER guidelines". To be practical at the construction site, the guidelines are not:

- Paperwork, books;
- Product installation manuals; these are provided by manufacturers;
- Theoretical protocols, procedures, standards;

Instead, the "INSITER Guidelines are designed as "interactive and living data sheets", thus avoiding lengthy reports/documents and allowing experts and users to extend, enrich and modify them continuously, as the guidelines are:

- Interactive, accessible on digital devices;
- Giving the process guidelines framework for self-instruction & self-inspection;
- Allowing practical implementation of the INSITER 8-steps methodology;

The INSITER Guidelines bring together documentation, principles, BIM data and measurement tools within the same framework of the INSITER 8-step methodology supported by IT solutions.

In practice, "INSITER Guidelines" are digital and available through 2 main IT solutions:

- a mobile application (users interface) that interactively guides the construction worker;
- the SharePoint platform (expert interface) that stores all data, including BIM models, pictures, database of data, including BIM models, pictures, database of components, checklists, etc.

The focus of INSITER is on prefabricated components and the needs of the modular construction process with respect to the elimination of energy efficiency and quality assurance gabs. The "INSITER Guidelines" respectively, address these Critical EeB Components (both building as well as HVAC/MEP systems) with the highest risk of errors during construction and the highest impact for quality and performance of the Energy-efficient Building (EeB).

The following critical components are selected:

Critical EeB Building components

- Foundation and ground floor
- Exterior walls and built-in elements
- Curtain walls
- Roof
- Connection between new and existing

Critical EeB MEP-HVAC components

- Heat pump
- Ventilation
- Solar hot water
- LED lighting

In light of this, the iPad application RE Guidelines is developed, to provide guidance to the worker on-site for the utilization of the INSITER toolset in their project. This application uses the INSITER 8-step model as its foundation, and gives guidance to the worker on-site for each step and for each of the 9 critical components. It also take into account the differences between new built and renovation. In total 144 (8 steps x 9 critical components x 2 for new or existing) guidelines are available. The guidelines in this app contain the main critical points, the key activities and the subjects where to pay special attention to. Further to this every guideline has project specific information or documentation. The RE Guidelines app gives the worker the opportunity to send feedback to the project manager about the guidelines and project specific information.

After a broad explanation of the 8-step methodology, there's an example of the Guidelines explained about heat pumps. See page

2.3 Toolset INSITER

This INSITER toolset is best characterized as a heterogeneous but interconnected set of software tools. In such a toolset concept it is especially important to structure and ensure the interoperability between these tools. To this end, the INSITER 8-step model is developed, which identifies eight distinct steps within the INSITER-augmented construction process and the INSITER toolset.

Figure 10 INSITER Framework

As depicted in the above figure, the following eight steps are identified:

- Mapping; creating geometric and semantic inventories of an existing building in a refurbishment scenario
- Checking; ensuring building components comply to specification and are undamaged delivered on-site
- On-site BIM; modelling and preparing BIM-models for on-site usage
- BIM-based AR; Augmented Reality as on-site guidance for the construction worker based on BIM
- Clash detection; determining the implications that on-site deviations have on the construction process
- Self-instruction; providing user-friendly self-instruction material to the construction worker
- Self-inspection; inspecting one's own and each other's work on-site and identifying deviations
- Final checks; keeping track real-time of the construction process through condensed information

Figure 11 INSITER BIM platform

The foundation for this 8-step model is the INSITER framework; a combination of three databases allowing the different software tools with the INSITER toolset to communicate and interact with each other.

2.4 INSITER collaboration platform

To provide access to and information about the INSITER toolset a central hub has been set up, the INSITER collaboration platform, which provides the end-user with a single access point to INSITER software tools based on the same INSITER 8-step model.

Figure 12 The INSITER collaboration platform

Due to the heterogeneous nature of this toolset the complete integration of all functionalities within one single tool was not feasible. The solution of cloud-based central access to such a toolset is in fact a strategy that is commonly employed throughout the contemporary software landscape.

Aside from the implementation of the INSITER 8-step model, the collaboration platform also serves as the central hub for content used by the various tools in the INSITER toolset; tools exchange files and data through the collaboration platform. These files are structured on the platform according to demonstration cases primarily, and the steps in the INSITER 8-step model secondarily.

Figure 13 INSITER Collaboration Platform with interacting and linked software per INSITER step

2.4.1 Technology

The INSITER collaboration platform is part of the INSITER Framework, which serves as the foundation of the entire INSITER 8-step model, and is achieved through the use of a Microsoft SharePoint 2013 site combined with a CMIS (Content Management Interoperability Services) interface.

2.4.2 Management

Aside from the conceptual and technological considerations regarding the INSITER collaboration platform there's a management strategy for the platform. Through these features the following user groups were defined and configured:

End-Users

The end-users (workers on site), of the INSITER toolset have read access to the full contents of the INSITER 8-step model, its underlying data, and documents on the platform to perform their work.

Platform managers

Platform managers (site managers), are given access, which enables them to (on top of the rights of end-users) edit the content of the INSITER 8-step model as well as full access to all documents on the platform.

Administrators

Full permissions have been allocated to the administrators, who ensure the technological infrastructure functions correctly and the end-users and platform managers can use the collaboration platform as intended.

The permission structure as outlined above together with the methodology behind content management and generation regarding the INSITER 8-step model ensures that the collaboration platform has become exactly that; a platform which is managed through the administrator, and a vehicle of conveying a coherent toolset to the end-user.

As every project is different and each partner in a project has its own experience and knowledge using specific software solutions it is expected that no single project will use every software application in the INSITER toolset. However, the heterogeneous nature of the INSITER toolset also allows for such usage of the provided software, where software tools can be substituted or even left out. Furthermore, the INSITER framework allows INSITER partners as well as external software providers to add software applications by using the interfaces the data sources in the framework provide. The combination of an interconnected set of software tools, an integrated data-backbone in the form of the INSITER framework, and the presentation of the INSITER toolset to the end-user through the INSITER collaboration platform makes valuable solutions for any project. Of course, such a heterogeneous but interconnected toolset presents a challenge in itself; it requires a framework to structure and categorize the separate tools into one coherent whole.

The INSITER General Process Chart

Software for Process-Steps

- Modelling Software: e.g. Autodesk Revit
- Syncro Pro
- Navisworks
- Desite MD
- Model Checker
- Version Comp.
- Model Issue Tracker
- Cyclone
- TruView
- 3D Reshaper
- NW Clash detection
- Design Coord. Analy.
- Design Coord. Syst.
- Clash Cube Creator
- BIM AR Vision
- BIM Mixed Reality

Information / Documents

All additional and updated information will be immediately available for updating design

- 2D drawings
- 3D models
- Time Schedule
- Point Clouds
- Deviation Analysis
- Clash Detection
- Detail drawings
- BIM models
- AR content
- Guideline references
- Check Lists
- ...
- QR-Codes
- Certificates

Site Worker

Factory / Supplier
- Confirm Order
- Production / Prefabrication
- Upload QR / Certificates

Project Manager
- Approval of BIM content: Energy, Cost, Planning — Not ok / ok
- Approval of BIM: Semantic & Attributes — Not ok / ok
- Approval of BIM: Geometry (Deviation) — Not ok / ok
- Coordination Geometry (Clash Detection) — Not ok / ok
- Place Pre-Fab Order

BIM Manager
- Link Information
- Create Model Checks
- Perform Model Checks
- Create Mesh of BIM model
- Combine Mesh & Point Cloud
- Perform Deviation Analysis
- Perform Clash Detection
- Create AR content
- Upload BIM & AR content

Experts (Energy Engineer, Calculator, Time Scheduler)
- Request for Revision
- Create Design Content (Energy, Cost, Planning)
- Upload Energy, Cost, Planning information

Designer
- Create Design
- Attributes Validation
- As-Is Geometry Validation
- Design Geometry Validation
- Pick relevant Information from Guideline
- Upload Detail information

Surveyor
- Create Laser Scans
- Post-Process Laser Scans

START

Guide-lines

Design Phase

Figure 14 The INSITER general process flow chart

INSITER prevents:

1: Errors due to lack of time for construction
2: Errors due to wrong delivered / damaged components
3: Errors due to bad preparation / insufficient information
4: Errors due to different site situation
5: Errors due to bad performance
6: Bad project management due to outdated information
...

INSITER On-Site App:

The INSITER On-Site App consists of several components supporting the INISTER's eight-step-methodology.

Following applications are combined in the app to guide the user through the different process steps during the construction phase:

RE Maintenance
RE Site Inspection
RE Construct
RE Dashboard
BIM Viewer
BIM AR Vision
BIM Mixed Reality
RE Guidelines

Directly updated on INSITER SharePoint

- Delivery Form (Check List)
- Self-Inspection Form (Check List)
- INSITER Dash Board Information will be retrieved directly from INSITER SharePoint

INSITER SharePoint

1,3,4 · 2 · 3 · 1,4 · 3 · 3 · 5 · 5 · 6

Prepare Apps

Get information about task

Validate components via QR-code

Deliver Prefab Panels

Claim Replacement

Get relevant information from BIM

Use of BIM based Augmented Reality

Getting instruction about Clashes to be solved on site

Get instructions about tasks (AR, Guides, Videos)

Perform task

Verify tasks via Checks Lists

Can be directly adjusted

Verify energy, cost and planning (compared to design) via Dashboard

END (of iteration)

ok / Not ok / Next task / anyways / yes / no

Construction Phase

INSITER methodology
Mapping
Checking
BIM on site
BIM based AR
Clash Detection
Self-Instruction
Self-Inspection
Final Check

Figure 15 The INSITER general process flow chart

3 8-Step methodology Step-by-Step

3.1 Step 1: Mapping

Figure 16 Mapping within the INSITER 8-step model

Step 1 is mapping the actual conditions of the construction site. For example identify the correct working area (floor/room/space) before starting with installations and capture the actual on site conditions.

In contemporary construction a large part of construction work concerns renovation projects. For such projects, it is essential that a thorough and reliable assessment of the current or starting situation is attained before starting to plan and carry out construction work.

The INSITER toolset facilitates this requirement in this first step within the 8-step model: Mapping, a process of inventorying (both geometrically and semantically) the existing building and capturing the inventory in data. This is done through the post-processing, conversion and augmentation of raw data. It should be noted that this step within the process is only relevant in refurbishment scenarios, and therefore is not

applicable within a new-built context.

Use-case

As the activities within this step are technical and suitable for specialists only, the envisioned users of the tools provided within this step are meant for inspectors, technicians, and geometric specialists. The application of these tools is a mixture between on-site and off-site usage; while the inventorying of the building in question is an on-site activity (the scanning or inventorying of building components), the post-processing and interpretation of the raw data takes place off-site.

Situation before INSITER

A contemporary for creating a (geometric) inventory of a building is to perform a point-cloud scan. However, there are still large challenges to overcome once a point-cloud scan is performed to attain a BIM-model from it. This is due to the very different nature between a point-cloud scan and a BIM-model; the former is granule (point)-based, while the latter is object-based. Moreover, through a point-cloud scan one does not attain semantic information about the building (components) that are scanned, while this knowledge is indeed critical. For example, the condition of existing and to be refurbished building components is essential in a refurbishment scenario.

INSITER added value

In comparison with the pre-INSITER situation, the INSITER toolset creates value through the utilization of three distinct software tools with regards to mapping. These tools can be characterized as solutions for:

- Point-cloud post-processing
- Point-cloud visualization
- Mesh generation
- Condition assessment

Figure 17 The INSITER collaboration platform offers in the first step (Mapping) access to the relevant tools (Cyclone, TruView, RE-Maintenance, 3D Reshaper, Design Coordination System). Relevant documents can be uploaded.

Point-cloud post-processing

Leica Cyclone is a laser scan post-processing tool, which is required to prepare the point clouds taken from a laser-scanner on site for further processing. Even though this tool has not been developed or adjusted within the INSITER project, the Leica Cyclone tool marks a very important process step to get use of point clouds gathered with Leica laser-scanners. This software is required to post-process the collected information, to purge them and to align the several laser-scans with each other. The software has to be used off-site by designers and employees of a surveying department to prepare the data of the point clouds for further processing. The scans taken will be evaluated and possible errors (like duplicated measuring points due to mirroring effects of glass windows) can be eliminated. Several point clouds can be merged and brought together to handle them as a single point cloud.

After aligning and grouping several point clouds, it is required to evaluate the grade of error, which occurs in the combined model. By checking several error values listed for all connected point clouds, it is easy to identify combinations which have a critical effect. By eliminating those connections and combining those separated scans with other scans the results of merged point clouds can be optimized.

The result of post-processing concerning the laser-scans taken will be an optimized, merged point cloud, which reflects the on-site situation in an optimal way.

Figure 18 The resulting optimized and merged point cloud

Point-cloud visualization

Laser scans provide a huge source of information about geometrical details of the as-is situation. On the other hand, it is hard to provide such information to a site team due to the amount of data. Therefore, options to provide the given information are required. Leica TruView provides the option to link the geometrical information of laser scans with the optical information of photos taken while performing a laser scan. This provides the required solution to hand over data to the site team. While the TruViews will be created off-site, it resizes the data to a suitable file size.

- To provide the given information in a most user-friendly format, the TruViews have been adjusted to combine photo information, information about the Index of Reflectivity and the geometrical information. BIM managers will be enabled to directly include additional information about the site into the TruView and provide the information to the site team.

- Leica TruView is an easy to use plugin for Microsoft´s Internet Explorer. It provides the geometrical information of the laser scans and uses just the images for visualization, which have been taken by the laser scanner during the scan process. Therefore, the file size is greatly decreased. It is possible to view the available information from the laser scanner´s point of view of each scanning location.

Figure 19 Viewing available information from a laser point of view in Leica Truview

Measurements can be performed directly in the TruViews and can be included as annotations. Additionally it is possible to add further information like hyperlinks or external documents.

Figure 20 Measurement tools are included in the viewer

Mesh generation

There is a common misunderstanding that performing laser scans automatically leads to sufficient BIM models. The process to transfer the geometrical information from point clouds to 3D models is very labor-intensive. Therefore, 3D ReShaper has been identified as a tool, which speeds up this process by providing very specific tools for post-

processing point clouds. This tool eases the process of creating Digital Terrain models, extract specific areas from the point clouds and transferring them to AutoCAD and Revit for modelling and to perform deviation analysis with relatively small effort. Other software solutions are limited regarding the handling of several point clouds, where the 3D ReShaper has been identified to be the most powerful solution to access huge amount of geometrical information with good performance. Designers and BIM Managers will be enabled to post-process the data off-site to validate their BIM models and enhance the models by adding additional relevant information.

- Hexagon's 3DReshaper is a software application that enables the user to access information of point clouds and to prepare them for 3D tasks. Within the INSITER toolset it is used for creating digital terrain models (by creating meshes from the point clouds), to do deviation analysis and to create 3D objects out of the point information.

- The created models and digital terrains allow the user to create 4D simulations and to perform clash detection against MEP components.

Figure 21 Figure 10: Creating 4D simulations

Condition assessment

In order to attain a more complete picture of the existing situation, aside from the geometric component of it, it is also necessary to perform a condition assessment of the existing building components. After all, it is critical to know not only the geometric information of building components but also the state which they are in in order to accurately design, plan and estimate costs of the construction process. To this end, the software tool RE (Real Estate) Maintenance, an integral solution for the condition assessment of the building components and installations, developed by INSITER partner DMO is used. This software tool is meant for technicians, inspectors and maintenance specialists. It provides the following step-by-step functionalities:

Inventorying a building

Before the condition assessment survey can be done, an inventory (registration of units and quantities of the relevant building construction parts) is performed. This inventory is usually performed by a combination of off-site desk research, evaluating existing drawings and technical information about the building, combined with a physical on-site inspection. The RE Guidelines app helps the worker to identify the critical points, the key activities and the subjects to pay special attention to. The RE Maintenance app gives the worker the checklists for the condition assessment.

Figure 22 Inventory of the Pisa demonstration case in RE Maintenance

Figure 23 Assessing the condition of the building construction parts

Defining activities for defects

Once the extent and intensity of defects have been defined, the next step is to define activities in order to repair the defects in order to attain a building component state that is deemed acceptable. For each activity a cost is calculated through the associated quantities for the inventories, coupled with a price list that defines a cost for each activity.

![INSITER INTUITIVE SELF-INSPECTION TECHNIQUES]

Generating multi-years maintenance plans

The total costs involved with the follow-up actions from the inspections can be presented in a multi-year maintenance plan. A multi-year maintenance plan takes into account the duration, frequency, extent and costs of the activities defined while inspecting a building, and present a coherent overview of these activities over the short and long-term future.

Figure 24 Cost involved with maintenance activities captured in a multi-year maintenance plan

The generation of a multi-year maintenance plan takes place when the inspection(s) are completed and activities have been defined. Once this is the case, such a plan is generated off-site as input for the subsequent steps in the INSITER 8-step model. The RE Guidelines app and the RE Maintenance software can also be used for mapping the site and foundation situation for new built buildings

Figure 25 RE Guidance app with general guidance and project specific information for the Delft use case

Figure 26: Inventory of the steel foundation for the Delft Demonstration case with RE Maintenance

User manuals Step 1 in INSITER:

https://cmis.demobv.nl/insiter/Manuals/Forms/AllItems.aspx?RootFolder=%2Finsiter%2FManuals%2F1%2E%20Mappin
g&FolderCTID=0x0120005C21D6ACB1F3E149B50A9C7B37A2F7A6&View=%7B0405C740-3FC5-4290-95F2-
9C3828FCEC6C%7D&InitialTabId=Ribbon%2ERead&VisibilityContext=WSSTabPersistence

Figure 27 Example of Building process step 1

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name		SUB-task name(s)
1	Mapping actual technical conditions of the site and building, and performing economic valuation of the property and land; capture the requirements and compare them to as-is situation	Map actual technical conditions of the site and building	Deliver 2D/3D drawings (latest IFC BIM model)	1.1
		Perform economic valuation of the property and land	Perform geometric checking of the building Deliver a usable 3-D scan to the architect for BIM	1.2

		Capture the requirements and compare them to as-is situation	Deliver: verification of the deviations of the existing concrete structure which influence the thermal performance of the new prefabricated panels	1.3

Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competence)
1.1 Building owner			Deliver 2D/3D drawings (latest IFC BIM model)
1.2 3D-scanner	How to work with 3-D laser scanning; understanding pointcloud data processing	The parts of the 3-D lasers can (areas of interest) of the facade, which are relevant for replacement with prefabricated panels	Perform geometric checking of the building Deliver a usable 3-D scan to the architect for BIM
1.3 Building engineer			Deliver: verification of the deviations of the existing concrete structure which influence the thermal performance of the new prefabricated panels

3.1.1 Conclusion

Figure 28 Mapping within the INSITER 8-step model, including the output to the next INSITER step(s)

In the first step of the INSITER 8-step model the foundation is laid to provide the possibility to use the INSITER toolset for mainly refurbishment scenarios. This is done through a dualistic approach of mapping both the geometry and semantics of the existing building. The results of this approach are post-processed point cloud scans made suitable for, amongst others, visualization, meshes generated based upon these point clouds to facilitate a subsequent BIM-modelling process, and the capture of semantics regarding the condition of building elements.

It is in this combination of geometry and semantics where the innovation of INSITER lies with regards to this first step in the INSITER 8-step model. In the following steps, it will be elaborated how this attained data and knowledge is used.

3.2 Step 2: Self-inspection during purchasing, production and delivery

and checking of prefab ordered components.

Figure 29 Checking within the INSITER 8-step model

Figure 30 QR reader and digital checklist

Opportunities for the usage of IT-technology and innovative processes present themselves very early, as early as during the fabrication of the components in the factories where they are made, or in central depots where such components are stored. Inspection of building components takes place at an early stage within the INSITER 8-step model.

Figure 31 The INSITER collaboration platform offers in the second step (Checking) access to the relevant tool (RE OnSite app and RE Guidelines app). Relevant documents can be uploaded.

Use-case

The inspection of building components is envisioned to be done by (sub)contractors and/or project supervisors before the actual construction of the building starts. The check of the correctness of the delivered prefab elements and all the additional material to mount the prefab elements will be done on-site. The prefab elements are also checked for transport related damages. In this stage storage requirements are given for all the material to prevent damage on-site. Furthermore it must be avoided that incorrect elements and connection material are sent to the building site. Valuable time and resources will be lost in the process of correcting wrong shipments.

Figure 32 Application of QR code scan and identification of the panel at IFC level

Situation before INSITER

In contemporary construction it is unavoidable that a certain percentage of the building components that will become the building together has a defect. Unfortunately, the identification of such a defect often occurs while the construction process is already underway, sometimes even at the moment when a building component is to be installed. When a defect is identified at such a late stage this can dramatically influence the construction process and planning, potentially causing delays and additional costs.

INSITER added value

To create the possibility to perform inspections on building components at an early stage, the RE OnSite app was developed by DMO for iPad-devices. This application contains, among others, the features required to perform such an inspection.

The RE OnSite app is fed with the right templates, planning, questionnaires and documents by RE Opname. This is prepared off-site. The RE Guidelines app helps the worker to identify the critical points, the key activities and the subjects to pay special attention to.

Figure 33 RE Guidance app with guidance for step 2 checking for new built.

An inspection with the on-site RE ONSite application can be broken down into the following steps:

Identify a building component

A QR-code is applied to each building component as a method of unique identification. This QR-code can then be scanned in the iPad-application, providing an easy way of linking an inspection to a specific building component

Figure 34 QR-code reader for product identification

Answer the questionnaire

The building component that was identified through its QR-code can now inspected. This is done though a questionnaire tailored to the specific component.

Figure 35 Checklist for self-inspection

Making observations

Apart from filling in the questionnaire the inspector can also register observations, defects and escalations with text, GPS coordinates, timestamp and pictures with drawing possibilities in order to inform the project leader about the situation.

Escalation

In case the inspector determines the findings of the inspection should be escalated to the project manager, he/she is able to immediately send an email to the project leader informing him/her of the inspection. The scanned QR tag is automatically added to a new email so that the project leader will know exactly to which part the email refers, and therefore is privy to all information regarding this part.

Figure 36 Picture with location, timestamp and drawing support

Figure 37 Picture with location, timestamp and drawing support

User manuals Step 2 in INSITER:

https://cmis.demobv.nl/insiter/Manuals/Forms/AllItems.aspx?RootFolder=%2Finsiter%2FManuals%2F2%2E%20Checking&FolderCTID=0x0120005C21D6ACB1F3E149B50A9C7B37A2F7A6&View=%7B0405C740-3FC5-4290-95F2-9C3828FCEC6C%7D

Example of Building process step 2

Figure 38 Example of Building process step 2

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
2	Self-inspection at procurement, production and delivery of prefab components	Self-inspect at procurement	Order the prefabricated panels according to planning
		Self-inspect at production	Add the right QR-code to the prefabricated panels
		Self-inspect at delivery	Transport the prefabricated panels by using the QR-code to the right position with tablet and BIM-model

Sub-task name(s)	Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competences)
2.1	Building site manager			Order prefabricated panels according to planning
2.2	Production worker factory			Add the right QR-code to the prefabricated panels
2.3	Construction worker	Where to store and install the prefabricated panel according to the BIM-model; how to work with the QR- code	The correct storing place of the prefabricated panels gives an organized building process (by using QR-code)	Transport the prefabricated panel by using the QR-code to the right position with tablet and BIM model

3.2.1 Conclusion

Figure 39 Checking within the INSITER 8-step model, including the output

By providing the (sub)contractors and/or project supervisors with a method of identifying defects to building components at an early stage, the INSITER toolset reduces the risk of costly delays during the construction of the building due to building components being damaged, not being made to specification, or simply being missing. This makes the planning, scheduling and cost estimation of the construction process more accurate. The BIM-based methodology to attain these essential components in a construction process is the subject of the next step with the INSITER 8-step model.

3.3 Step 3: On Site BIM: Modelling the (existing) building, terrain, environment in a building information model (BIM)

Figure 40 Comparisons between real live situation and the BIM model: general outside and inside views on the façade panels

Figure 41 Comparisons between real live situation and the BIM model: corners in a corner room and middle room

In the BIM model at INSITER, extra attention is paid to investigate the following critical components:

- Architectural critical components:
    - Foundation and ground floor
    - Exterior facades and elements to be built in, such as glazing
    - Glass facades
    - Roof
    - Connections between new construction and existing building
- MEP/HVAC critical components:
    - Heat pump
    - Ventilation installation
    - Solar water heater installation
    - LED-lighting

Figure 42 On-site BIM within the INSITER 8-step model

In step 3 of the INSITER 8-step model the foundations are laid for the application of BIM on-site as well as the utilization of BIM in planning, scheduling and cost estimation. The concept and utilization of BIM is right of the core of the INSITER 8-step model; the vast majority of steps in this model utilize BIM as a base to create value upon. Therefore, this is an extremely critical step in the model.

In the case of a refurbishment scenario, the execution of step 1 (mapping) in the INSITER 8-step model has resulted in post-processed point-cloud scans and meshes generated from these point-cloud scans. If this is the case, these serve as input to this step within that model.

Figure 43 The INSITER collaboration platform offers in the third step (On-Site BIM) access to the programs. Relevant documents can be uploaded.

Use case

The software that is used within this step in the INSITER 8-step model is primarily intended to be used by BIM-managers, although many tools have obvious uses for other construction professionals such as architects, project managers and contractors, but require a degree of BIM-knowledge to use as is intended. This is mainly due to the

information requirements that various software tools impose upon the models used throughout this step. These requirements differ from tool to tool, and might even be conflicting on some aspects. Therefore, it is necessary that a BIM-manager coordinates the exchange of information from tool to tool and from professional to professional in order to attain a BIM-model suitable for on-site usage in the subsequent INSITER model steps, as well as performing BIM-based analysis.

The usage of the software described in this step primarily has an off-site nature. This may seem counterintuitive at first, as the title of the step is 'On-site BIM'. However, this title should be seen in the light of the outcome of this step, a BIM-model ready for on-site usage, and not as a characterization of the tools used within the step.

Situation before INSITER

The application of BIM within the construction sector is not novel in itself; this is increasingly adopted by parties from practice. However, the communication through and particularly the requirements with regards to BIM are often quite different, leading to miscommunication and multiple (separate) BIM-models used by various parties.

INSITER added value

The value that INSITER creates within this, digital, aspect of the construction sector is to present an integral vision for the usage of BIM.

This vision consists of the following activities:

- BIM-modelling
- Ensuring the BIM-model is suitable for (on-site) usage
- Visualization
- Planning and scheduling
- Cost estimation

In the following subchapters the software tools that support these activities will be elaborated upon.

3.3.1 BIM-modelling

Autodesk Revit was chosen as the BIM-modelling software package to create BIM models for INSITER. The intension was to find a solution which is very common and wide-spread in the construction sector to enable easy transfer of the results of INSITER to other projects. Crucially, it provides the possibilities to export the BIM-model to IFC2x3 as well as IFC4 file formats, the most common collaboration and exchange format with regards to BIM in contemporary construction. It is important to stress that other software solutions will be suitable as well as long as the requirements towards the BIM-models, defined by the subsequent software tools and analysis methods, are met. It is the responsibility of the BIM-manager to ensure that this is the case. BIM modelling is an off-site process, which will be performed by architects, designers and BIM managers.

Figure 44 Creating a BIM model in Autodesk Revit

3.3.2 Ensuring the BIM-model is suitable for (on-site) usage

Autodesk´s Navisworks Manage is mainly used to perform Clash Detection in INSITER. One of the most powerful benefits is the possibility to import almost every kind of 3D information, which means that all related processes can easily transferred to other projects. Navisworks will be used off-site to perform clash detection and to identify critical issues, which should be solved before construction to avoid errors on-site.

Navisworks provides several options to define selections of BIM objects. On the one hand, it is possible to directly select specific elements and group them to selection sets, on the other it is possible to search for attributes and specific values to define search sets. This enables the BIM Managers to configure all BIM data according to the needs of the related use cases.

Figure 45 Horizontal sectioning in Navisworks

This enables the user to create clash batches as required in the Clash Detection tool. Clash batches define 3D elements which should be verified in a geometrical way against each other. Interfering objects will be highlighted as clash results for further design coordination.

Figure 46 Vertical sectioning in Navisworks

It has to be mentioned that that the geometrical check is done automatically, but performing clash detection, which means to post-process the automatically identified conflicts, is a manual process and requires engineering skills.

Conflicts have to be evaluated, whether those have to be discussed or if they can be ignored and on the other hand, conflicts have to be combined in a reasonable way (two parallel heating pipes, which are interfering with a sanitary pipe have to be considered as a single clash instead of two geometrical conflicts)

Figure 47: Post-processing clash results

Through clash detection is it possible to recognize unfeasible or undesirable outcomes of the construction process at an early stage. However, in the light of the on-site deployment of the BIM-model it is also equally important to ensure the model itself contains all information necessary for subsequent steps in the INSITER 8-step model.

Ceapoint´s "Desite MD" is used to perform model checks in the INSITER project.
The API, which comes with the software, offers a variety of tools to enhance the functionality of the software and to adjust the interface to the given requirements.

Figure 48 Desite MD, a customizable tool applied for model checking

For all BIM elements, it is possible to examine the related attribute information, which is connected to a specific item. Which information will be provided can be defined in options menu. This enables the user to choose the required information.

Figure 49Figure 31: Viewing information for a specific BIM element

Desite MD´s model checker provides several model checks which enable the user to check the BIM-model for errors.

Starting with an integrity check of the specific BIM objects, going through checking whether the objects have unique IDs, up to user-defined checks, which allow proofing the spelling of specific attributes and/or the values.

Figure 50 Desite MD's model checker functionality

Beside those model checks, which proof the model against clearly defined rules, there is another validation tool: the Issue Tracker. This tool is a plugin, which has been developed to be integrated in Desite MD. The issue tracker is intended to keep track on issues which have to be clarified, which are not directly related to specific model definitions.

For an introduction watch the PowerPoint 'Demonstration BIM Model Validation with Issue Tracker' (03_Issue Tracker_Health Care Centre, Cologne.pptx) from the project Health Center Cologne (Germany).

Figure 51 Issue checker to keep track on all the issues to be clarified

The example to the right shows an issue which is connected to a façade panel. Currently the model shows the information which was available when starting the modelling process. Since there were no decisions taken about the final design of the prefabricated panels, it is still open to clarify the final design. Such an issue cannot be identified via the model checker, because there are no clearly defined rules to check the correctness of the façade design.

Figure 52 Example of an issue related to the façade panel

Despite this limitation, the combination of clash detection and model checking ensures the suitability of the BIM-models used in INSITER for the, primarily on-site, tools in subsequent steps in the INSITER 8-step model as well as tools that build upon this BIM-foundation in this step.

For an example of quality checks on BIM-models watch the PowerPoint demonstration (03_ModelChecks_HCC_2017-11-10.pptx) from the project Health Centre Cologne (Germany).

3.3.3 Planning and Scheduling

For creating 4D simulations, where the fourth dimensions 'time' is added to the traditional three geometric dimensions, Synchro PRO, a 4D BIM construction scheduling and project management software, has been chosen to be the most suitable solution.

Synchro PRO is a tool for 4D scheduling, which means that time schedules will be elaborated directly using BIM models. This process is slightly different to common procedures, which generally create time schedules separated from the BIM models. The benefit for using Synchro 4D is that BIM model and time schedule are matching their corresponding Work Breakdown Structure. This avoids loss of information like missing attributes due to adjusting the BIM models by splitting BIM objects into two according to a separated time schedule. On the other hand, the common way to use already existing data is possible as well. Creating 4D simulations is an off-site process, which prepares the optimization of construction processes and validating aimed construction sequences. The 4D simulations will be used off-site for validation and on-site to provide 4D instructions to the site-workers.

If BIM models are available, those will be imported to Synchro PRO together with the existing time schedule. By adjusting the time schedule to match the Work Breakdown Structure of the BIM model (respectively the other way round), the model and the schedule will be prepared to be connected.

Figure 53 4D Synchro PRO for 4D simulations

After connecting BIM with the time schedule, it is possible to define viewpoints and camera movement for the to-be-created 4D simulation, which finally can be exported as an animation file for further (on-site) usage.

Figure 54 Creating an animation of the 4D simulation

For a SynchroPRO basic training see: Synchro Basic Training v5.1.pdf

For a SynchroPRO scheduling training see: Synchro Scheduling Training v5.1.pdf

3.3.4 Cost Estimation

The application that is used for calculating costs varies from project to project. One of the contributing factors to this is the availability of already purchased software and the IT-knowledge of the personnel of certain software tools.

There are many software packages available for calculating cost with BIM integration. On the one hand, some of them are focused on specific countries, but on the other hand there are also solutions that are targeting a worldwide distribution.

CostOS is a commercial application; there is no extension or adjustment created for CostOS within INSITER. The reason for selecting CostOS is its tight integration with BIM, specifically IFC2x3 as used within INSITER and the usability of the application for different countries. The user is expected to be a specialist applying cost estimation on a BIM model; although the tool is intuitive to use making accurate cost estimations requires specialized knowledge and experience with the applications used.

User manuals Step 3 in INSITER:

Example of Building process step 3

Figure 55 Example of Building process step 3

Qualifications: Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
3	Modelling of the [existing] building, site and surroundings in Building Information Model (BIM).	Model the [existing] building in Building Information Model (BIM).	Deliver a design for an energy-efficient façade
			Deliver an engineered design for an energy-efficient façade without thermal bridges
			Deliver HVAC installation design, according to the new façade with wished indoor climate

			Design according to the input of architect/ building physicist, building regulations

3.3.5 Conclusion

Figure 56 On-site BIM within the INSITER 8-step model, including the output to the next INSITER step

This chapter has outlined the modelling and preparation of BIM-models within INSITER, to make them suitable for on-site application as well as performing BIM-based analysis before the start of construction. The methodology to achieve this is best-described as a holistic BIM-vision; a structure of interconnected tools with a clear plan for and verification of the data exchange between these tools in order to achieve the envisioned usage of BIM within INSITER.

INSITER has created the following added value:

• Provided proof that a heterogeneous collection of commercially available tools is can be utilized to support a BIM-vision through careful selection of these tools and a data exchange plan.

• Where necessary, tools and libraries were developed in INSITER in order to further augment the collection of software tools, or to fill the identified software gaps where needed. Examples of these are the Online 3D viewer and the area calculation library for cost calculation.

- Recommendations are made where existing technology did not prove to be sufficient or where a conceptual solution still needed to be developed. Examples of this are the superimposition of textures on IFC-models and the alternative solution for area calculation. Furthermore, where these concepts and solutions developed within INSITER are relevant in a broader context, it has been indicated that the source code for the software implementation will be made public.

The BIM (IFC)-models that are generated and validated within this step in the INSITER 8-step model will be extensively used and built upon in the following steps.

3.4 Step 4 BIM based AR: Create and deploy BIM-based AR (Augmented Reality) in a project for self-instruction and self-inspection

Figure 57 Visualisation of BIM with AR

Figure 58 BIM-based AR within the INSITER 8-step model

This chapter will give a short overview of BIM-based Augmented Reality (AR) developments for self-inspection and self-instruction on mobile devices for INSITER.

The BIM-based AR solutions are based on the output of step 3, On-site BIM, in the INSITER 8-step model. In this step BIM-models were created and exported to IFC. These same IFC-files are used as the input for the BIM-based AR solutions that will be described in this chapter.

Figure 59 Simulation of BIM-Based Construction Process for Self-instruction in AR

Figure 60 The INSITER collaboration platform offers in the fourth step (BIM-based Augmented Reality) access to the programs. Relevant documents can be uploaded

3.4.1 Use-case

The solutions developed in this step within the INSITER 8-step model are meant to be directly used by the construction workers on-site through the usage of mobile devices. Therefore, this is the step where the important transition is made from virtual environments (steps 1 through 3) to augmented reality, the mixture of virtual and real environments.

3.4.2 Situation before INSITER

As previously identified in step 3, the utilization of BIM in the construction sector is not novel; in contemporary construction the usage of BIM is widespread and common. Similarly, augmented reality, while certainly a newer concept, is also not novel in itself and has been adopted at a rapid pace in recent years, leading to successful

employment of the technology in many applications, some of which were intended for and indeed successful among the general public. In maintenance work AR technology becomes more popular. The innovation in step 4 lies in the combination of these two, existing, concepts and applying it on-site in the construction sector, with the aim of providing a guideline for the construction workers on-site.

3.4.3 INSITER BIM AR Vision App

The INSITER BIM AR Vision App is designed to visualize extensive or complex BIM models with referenced planning or instrumentation data in AR. The developments are based on the Fraunhofer instant3Dhub platform, which allows a server or client based visualization of large geometry models. Fraunhofer computer vision based tracking and enhanced model tracking algorithms including BIM visualization functionalities and data referencing will provide a comprehensive BIM-based AR solution for INSITER.

Figure 61 On-site INSITER BIM AR Vision App Screenshot (Tracking Development and Tests)

With the help of this newly developed AR solution, the actors on-site will be able to display and select individual 3D building elements from complex BIM models for self-inspection as well as view linked and referenced planning data such as available planning documents, instrumentation data or self-instruction videos. The main focus of the application is on in-situ visualization of building parts or equipment to be installed as well as BIM-based AR evaluation of defined BIM objects concerning the correct location and placement of the real construction objects. Thus, the application will help to identify construction errors and inconsistencies on-site.

The functionalities of BIM AR Vision App for self-inspection and self-instruction are:

- Identification and visualization of complex BIM or CAD elements and parts in MR
- Access to referenced self-instruction, self-inspection data or planning information on INSITER SharePoint (available guidelines, instrumentation data, etc.)

- In-situ visualization of building parts or equipment to be installed
- Evaluation of defined BIM objects and for example prefabricated façade panels concerning e.g. the correct location and construction position
- Analysis of construction errors and identification of inconsistencies with verification of the assembly location and placement of BIM elements

Figure 62 Visual comparison example between BIM-based MEP model and the planned to-be target state and installation of the MEP system to be conducted with MS Hololensl

3.4.4 INSITER HoloLens BIM-based Mixed Reality App

The latest technologies are applied within INSITER, which enable interactive visualizations of BIM models with smart glasses and mixed reality systems such as the MS HoloLens. The INSITER HoloLens BIM-based Mixed Reality App will provide an additional hands-free solution concerning detailed BIM model evaluation for self-inspection concerning defined on-site environments and BIM models. Within INSITER, the focus is on validation of technical building services such as MEP or HVAC systems on-site. The head mounted see through display technology in combination with spatial mapping based object tracking will provide enhanced hands-free self-inspection and self-instruction capabilities.

INSITER Solutions	Visualized Planning Data	Screenshots

INSITER BIM AR Vision:

Complex BIM Models, Planning and Instrumentation Data

AR Solution for extensive and complex IFC BIM models for on-site self-inspection with referenced planning, self-instruction documentation and instrumentation data (with tablet computers)

INSITER HoloLens BIM-based Mixed Reality:

Detailed BIM-based 3D scenes, including e.g. MEP systems etc.

Detailed 3D scenes and BIM model evaluation for on-site self-inspection or self-instruction (with MS HoloLens)

INSITER BIM-based Self-Instruction AR:

Detailed BIM-based Process Guidance and Simulation

Detailed self-instruction simulation and visualization (with tablet computers, smart glasses or MS HoloLens)

Figure 63 BIM based mixed reality

The focus of the INSITER HoloLens BIM-based Mixed Reality App is on:

- BIM model evaluation for self-inspection for detailed 3D construction environments. E.g. evaluation of technical building services such as mechanical, electrical, and plumbing (MEP) or heating, ventilation, and air conditioning (HVAC) systems.

- Visual comparison between virtual BIM model and real on-site situation

- On-site planning and validation of construction sites

- Visualization of architectural BIM models and evaluation in different scale levels

Figure 43: HoloLens Screenshots -

Left: Visualization and evaluation of BIM models on different scale levels.

Right: On-site application of INSITER HoloLens and BIM-based Mixed Reality App for evaluation of the MEP system installation

![INSITER logo - INTUITIVE SELF-INSPECTION TECHNIQUES]

The main focus of the application is on evaluation and comparison between the virtual model and the real on-site situation in mixed reality with the help of advanced spatial mapping. The "INSITER HoloLens BIM-based Mixed Reality App" can be utilized e.g. by advisers such as architects, technical installation advisers, structural engineers or other actors on-site such as installation technicians. One main functionality is the visualisation of on-site elements, which have to be evaluated, installed or removed for refurbishment works. Project managers can monitor the installation process and check if new construction elements or HVAC/MEP systems have been mounted correctly. Also the identification of possible clashes concerning planned BIM objects or HVAC/MEP elements with existing building parts that have not been considered in the digital BIM model is feasible. In addition, available process measurement data can be visualised and inform the actors on site about e.g. thermal bridges or acoustic leakages. The described tasks are supported with gestures and speech recognition enabling intuitive interaction with the virtual objects and the real environment. The use of the Augmented Reality can be seen in this video.

Recognition of real physical objects (based on BIM-data) or dedicated AR markers

Superimposition of digital objects and self-instruction simulation

Figure 64 Recognition of objects

Figure 65 Example of Building process step 4

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
4	Generating and deploying BIM-based Augmented Reality (AR) for self-instruction and self-inspection	Generate and deploy BIM-based Augmented Reality (AR) for self-instruction and self-inspection	Stock the wished instructions and inspections in coordination with the construction worker; instruct the software developer
4	Generating and deploying BIM-based Augmented Reality (AR) for self-instruction and self-inspection	Generate and deploy BIM-based Augmented Reality (AR) for self-instruction and self-inspection	Embed BIM and VR in Augmented Reality Extract BIM/ VR process information into self-instructions for construction workers on their smart devices Generate self-inspection modules for construction workers on their smart devices

Sub-task name(s)	Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competences)

4.1	Building engineer / buildingsite manager	Which instructions and inspections in AR are needed and possible fort the construction worker	Which instructions and inspections in AR are workable for the construction worker	Stock the wished instructions and inspections in coordination with the construction worker; instruct the software developer
4.2	Software developer	Structure of the BIM-model; how to change the BIM-model suitable for the AR device; incorporating BIM into the inspection software	How the construction worker can use the AR-device for self-instruction and self-inspection	Embed BIM and VR in Augmented Reality Extract BIM / VR process information into self-instruction for construction workers on their smart devices Generate self-inspection modules for construction workers on their smart devices

3.4.5 Conclusion

Figure 66: BIM-based AR within the INSITER 8-step model, including the output to the next INSITER step

In this chapter a novel way to support the construction worker on-site through the combined utilization of BIM-models, which is the output of the previous step in the INSITER 8-step model, and augmented reality, is summarized. The result of step 4 is the BIM-base visualization of complex situations. It is important to stress that this technology is not

envisioned as a blanket solution for the entirety of the construction process. The utilization of AR-technology is most suited to complex situations, such as the precise integration of multiple systems or installations; situations in which without visual aid the exact requirements could be unclear and therefore mistakes could be made.

Figure 67 Demonstration of MEP/HVAC systems in connection with AR pilot case application (FhG) (A: Complete BIM-model, B: Current Installation Status, C: New Pipes to be Installed)

3.5 Step 5: Virtual validation of quality and performance through BIM model control and clash detection.

Figure 68 Clash detection within the INSITER 8-step model

Although the BIM-models used within INSITER are thoroughly checked in step 3 of the INSITER 8-step model, it still can occur that once the construction process is started clashes can occur on-site. If this is the case, it is critical that the on-site workers and supervisors are supplied with information how this could have occurred, and how the on-site situation relates to the off-site model.

To this end, a second layer of clashing is introduced, which distinguishes itself from the clashing and model checking in step 3 by performing the clash detection on the as-built model; the way the building is actually constructed. Through this model and clashing, the implications of on-site deviations on the to-be-constructed or mounted building components can be identified.

Figure 69 The INSITER collaboration platform offers in the fifth step (Clash detection during construction) access to the programs. Relevant documents can be uploaded.

Use-case

The BIM-manager is the key actor in performing the clashes themselves and will be in close contact with the on-site team, particularly the supervisors, to discuss the on-site situation and its implications. The clash detection process itself is an off-site activity, but due to the close collaboration with the on-site team it has large on-site implications.

Situation before INSITER

In contemporary construction it is not unknown, although it is not common either, to perform BIM-based clashes. However, once on-site deviations from these (albeit realistic) theoretical models often have implications further down the line in the construction process.

INSITER added value

As previously mentioned in step 3 of the INSITER 8-step model the usage of Navisworks in the INSITER project is focused on the Clash Detection tool, which is available in the Navisworks Manage version. Performing clash detection is an off-site process, which will be performed by a BIM manager with the aim to optimize the design and avoid errors, which would be encountered during construction.

To further facilitate and enrich the clashing process and to provide more complete information to the on-site team two additional software tools have been developed: the Design Coordination Analyzer and the Clash Cube Creator. The combination and interrelation of these three software tools will subsequently be described in more detail.

3.5.1 Navisworks Manage – Clash Detective

- To create the definition of the clash detection the user has to specify which elements have to be checked against which other elements. Such a combination is called a clash batch. To verify the design of all MEP components against each other, for each combination a separate clash batch has to be created.

- In detail: if there are four MEP trades (HVAC, Electrical, Sanitary, Heating) available in the BIM model, there will be six clash batches in total (HVAC-ELEC, HVAC-SAN, HVAC-HEAT, ELEC-SAN, ELEC-HEAT and SAN-HEAT). Adding another trade will increase the amount of clash-batches to a total of ten (new trade against each of the already existing ones). Keeping in mind that generally there are a lot more trades in a common construction project highlights that it is a time consuming and error-prone task to set up those clash batches.

Figure 70 Setting-up clash batches is a time consuming and error-prone task

3.5.2 Design Coordination Analyser

One of the main goals of the Design Coordination Analyzer (DCA) is to ease the way of setting up the clash batches.

The DCA is a plugin for Navisworks Manage, developed in INSITER, which will lead the user through the whole process of the clash detection.

Trades will be defined at the start of a clash detection process. All related clash batches will be generated automatically based on those trade definitions.

Figure 71 Setting-up clash batches made easier using Design Coordination Analyzer (DCA)

- After those preparations, the user will be guided step-by-step through all required process-steps for performing a clash detection process.
- At the end the clash report will be generated and exported into a clash report exchange format (*.vdcs). This file will afterwards be imported into the Design Coordination System (DCS) for further coordination tasks.

Figure 72 Clash reports for further coordination tasks

3.5.3 Clash Cube Creator

- To forward clash information to on-site personnel the Clash Cube Generator has been developed. The Clash Cube Generator is a tool which collects the information from identified clashes in a clash detection process and transforms that information into small cubes. Those cubes will be automatically saved in a separate IFC-file including all related clash information. Clash cubes will be created off-site and will be forwarded to be used on-site.

Figure 73 Clash information stored in clash cubes

- The purpose of this file is to provide the clash information to the site-team. Its usage is twofold:
- Creating clash cubes directly after performing clash detection will allow the site-team to proof the identified clashes and to sort out which conflicts have to be discussed in a coordination meeting.
- Creating clash cubes after a performed coordination meeting allows transferring the decisions of the coordination directly on-site to solve those issues.
- The Clash Cube Creator is the connection between off-site clash detection and decision making and
- the on-site team.

Figure 74 General process of performing a clash detection

Figure 75 Process

User manuals Step 5 in INSITER:

https://cmis.demobv.nl/insiter/Manuals/Forms/AllItems.aspx?RootFolder=%2Finsiter%2FManuals%2F5%2E%20Clash%20detection&FolderCTID=0x0120005C21D6ACB1F3E149B50A9C7B37A2F7A6&View=%7B0405C740-3FC5-4290-95F2-9C3828FCEC6C%7D

Example of Building process step 5

Figure 76 Example of Building process step 5

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
5	Virtual validation of quality and performance by BIM Model Checking and Clash Detection; as well as value and process optimisation by Virtual Reality simulation	Validate quality and performance by BIM Model Checking and Clash Detection	Understand the clashes and what to do if help materials of the façade are not in place or not correctly assembled
		Optimize value and process with Virtual Reality simulation	Understand the detected clashes and deliver instructions for the construction worker

Sub-task name(s)	Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competences)
5.1	Construction worker	How to read the BIM model; how to use the AR device	The position of the prefabricated panel in the BIM-model; which materials of the façade have to be in place (visible in VR and BIM) before the prefabricated panel can be assembled; Are the help materials of the façade placed correctly to assemble the prefabricated panels	Understand the clashes and what to do if help materials of the façade are not in place or not correctly assembled
5.2	Building site manager			Understand the detected clashes and deliver instructions for the construction worker

3.5.4 **Conclusion**

Figure 77 Clash detection within the INSITER 8-step model, including the output to the next INSITER step

In this step, clash detection, within the INSITER 8-step models a process of on and off-site collaboration is proposed, supported by software tools. These software tools are a mixture of a commercially available clash detection program, a plugin for this program developed within INSITER to facilitate the process of clashing and an INSITER-developed software tool to ease communication between the off and on-site teams.

This process of collaboration aims to signal and act upon on-site deviations as quickly as possible and thereby preventing the need for ad-hoc measures at a later stage in the construction process to accommodate deviations that were previously undetected. In the next two chapters, the methodology for preventing deviations and recognizing and capturing them is addressed.

3.6 Step 6: Self-instruction
during the preparation and logistics of the construction site and during construction

Figure 78 Self-instruction within the INSITER 8-step model

In step 6, self-instruction, the INSITER toolset provides a novel method of instruction for the construction workers on-site. The basis for this approach is the digital and audio-visual instructions which are disseminated to and available for construction workers through an on-site software tool.

Figure 79 The INSITER collaboration platform offers in the sixth step (Self-Instruction) access to the programs. Relevant documents can be uploaded

Situation before INSITER

Each building component used in construction is, where necessary, supplied with instructions for the construction workers on-site. However, the relation of the instructions with the building component has to be identified by the construction workers themselves, and the instructions themselves can be located in varied places and can be both of digital as well as of physical nature.

INSITER added value

In order to provide self-instruction techniques to the construction worker on-site, the INSITER toolset provides an iPad application, RE OnSite as previously described regarding the second step in the INSITER 8-step model, checking. Self-instruction material can be a document with an instruction, a video or a step-by-step interactive software application. The construction worker is able to self-instruct him or herself by following the next steps:

- Make instruction available for on-site use in RE Construct

  The RE Construct, developed in Insiter, gets the information and documents from the Collaboration platform and displays it per project and critical component.

Figure 80 RE Construct with the instruction and additional documents for the self-instruction for the Delft demonstration project

- **Identifying the related construction part of a building**

  For on-site use the RE OnSite app is used by the worker. The self-instruction material often relates to a construction or installation part of the building. A construction part can easily be identified by applying the QR scanner, as previously described in step 2. If the building component, for whatever reason, does not have a QR code but it is known to which part of the building it belongs, the information related to that part can also be identified by selecting the corresponding building component in the 3D-viewer.

  This 3D model viewer presents the BIM-model previously modelled and validated within step 3 of the INSITER 8-step model to the construction worker, who selects the building component for which he or she wants to access the self-instruction material. This building component then becomes highlighted.

Figure 81 The identified building part is highlighted (green)

  Accessing documents, photos and videos for the selected construction part

  For every part, content can be added to the INSITER collaboration platform. This content can be documents, photos and videos. The relationship between the content and the construction part is simply made by adding a folder with the unique identifier (GUID) of that part as folder name. When a user clicks on a part of the 3D model, the SharePoint server is searched for a folder with the same GUID as the construction part and the content of that folder is listed on the tablet. The user can then select a certain document and it will be opened in a separate window. Multiple documents can stay open at the same time which supports easy and fast switching between the documents.

Figure 82 Accessing self-instruction material in the form of documents, photos, videos

Aside from self-instruction through the RE OnSite iPad-application, two other developments within INSITER should also be mentioned in this context.

- **AR-technology**

  Self-instruction is also supported by applying Augmented Reality technology. The technology and its application within INSITER are explained in step 4.

- **Step-by-step instruction creation**

  One type of self-instruction material is animated by step-by-step instructions. A detailed description of the step-by-step is available, as well as instructions how to use and install this application.

User manuals Step 6 in INSITER:

https://cmis.demobv.nl/insiter/Manuals/Forms/AllItems.aspx?RootFolder=%2Finsiter%2FManuals%2F6%2E%20Self-instruction&FolderCTID=0x0120005C21D6ACB1F3E149B50A9C7B37A2F7A6&View=%7B0405C740-3FC5-4290-95F2-9C3828FCEC6C%7D

Example of Building process step 6

Figure 83 Example of Building process step 6

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
6	Self-instruction during preparation and execution of construction site and logistics.	Follow self-instruction during preparation and execution of construction site and logistics.	Assemble the prefabricated panels with the instructions from a smart device

Sub-task name(s)	Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competences)
6.1	Construction worker	The dimensions and the position of the prefabricated panel in the BIM-model and how to work with the AR device which material is used to assemble the prefabricated panel in the facade	How to assemble the prefabricated panels in the façade according to the instructions from a smart device	Assemble the prefabricated panels with the instructions from a smart device

3.6.1 Conclusion

Figure 84 Self-instruction within the INSITER 8-step model, including the value created

This chapter has outlined the advancements that INSITER is making with regards to the self-instruction of on-site construction workers. This is done through a combination of a mobile (iPad) application, but is further enriched by the application of AR-technology and the creation of step-by-step instruction animation by an INSITER-developed application. The goal and expectation of this combination is that it will decrease the chance of deviations and/or defects occurring during on-site construction, by equipping the on-site workers with a single application containing, a portal to, all required self-instruction material.

3.7 Step 7: Self-inspection during construction, refurbishment and maintenance.

Figure 85 Self-inspection within the INSITER 8-step model

In step 7 of the INSITER 8-step model the INSITER toolset provides solutions to be able to carry out on-site self-inspection during the construction phase. The reasoning for such facilities lies, similarly to the previous two steps, in the prevention of unexpected delays due to human errors or material defects; the earlier such shortcomings are identified, the earlier they can be acted upon and prevent unpleasant surprises later in the construction process.

Additionally, INSITER also has attained experience with and developed upon a monitoring system for the commissioning and post-commissioning-phases in one of its demonstration cases, which will also be elaborated upon in this chapter.

Figure 86 The INSITER collaboration platform offers in the seventh step (Self-Inspection) access to the programs. Relevant documents can be uploaded

3.7.1 **Use-case**

The self-inspection tools provided are meant to be used on-site during the entire construction phase. They are meant as an active feedback loop for the construction workers carrying out the work on-site, not limited to one's own work but also as a mechanism to provide feedback among colleagues and all other involved parties (design, production, suppliers, etc.).

Situation before INSITER

In contemporary construction such explicit feedback and quality control as described in the introduction to this chapter are not commonly implemented. Inspection during the construction process itself is then often limited to the cases where something is unavoidably wrong and leads to concrete problems in the continuation of this process.

INSITER added value

On-site self-inspection

To avoid situations as described above, or at least identify and act upon them at an earlier stage, an inspection application was developed within RE OnSite, further adding to the integral solution that this application provides at various points within the INSITER 8-step model. The RE OnSite app interacts with the RE Construct software. The self-inspections are performed by filling out a self-inspection checklist. In order to do this, the following steps need to be performed:

- Prepare all the relevant checklists and information to conduct the self-inspection

  All the relevant checklists and information for the self-inspection comes from the INSITER collaboration platform. The RE Construct functions as an intermediate between the collaboration platform and the RE OnSite app.

Figure 87 The INSITER RE Construct with the critical components to be checked for the Delft demonstration project.

- Identifying the related construction part of a building

  The self-inspection checklists always relate to a building component. Such a component can easily be identified applying the QR scanner or by selecting it within the 3D-viewer on the mobile device as described in step 2 and step 6.

- Filling in the self-inspection checklist related to the selected building component

  When the construction worker has selected a building component through either methods, its properties are displayed. Next step, when the construction worker selects "self-inspection" a checklist becomes visible with

self-inspection questions related to that component. Besides filling in the checklist the user can also register observations, defects and escalations with text, GPS coordinates, timestamp and pictures in order to inform the project manager about the situation.

Figure 88 Self-inspection checklist

- Feedback to project manager via RE Construct of the inspection

The supervisor or site manager receives the input from the onsite inspections in the RE Construct software.

Figure 89 Observations from onsite inspection available in the RE Construct tool. A status report gives an overview of the inspections per critical component.

3.7.2 **Post-commissioning self-inspection**

Apart from the aforementioned tools for self-inspection, there is a widely used and reliable self-inspection method for monitoring, mainly being used for commissioning and post-commissioning stages. Monitoring is the process by means of which the quality or features of the building are obtained. Usually, monitoring is the collection of dynamic data, on a periodic basis, of the building's behaviour. That is why its usage is limited to the operational stage of the building, but it provides surveillance procedures for the building elements, particularly HVAC and comfort parameters.

Thanks to monitoring, malfunctioning may be detected in advance which also contributes to energy efficiency and cost savings. One clear example is when a boiler is suffering degradation, which is very difficult to determine if no monitoring of the performance parameters is implemented. Hence, within INSITER, the purpose is covering the operational stage (or post-commissioning) of the building. Once the building is delivered (commissioned), monitoring helps the maintenance and surveillance, which should be not neglected. It is true that most of the errors may be solved during construction phase, but it is also demonstrated that monitoring (and fault detection, e.g. degradation of a boiler) may save up to 20% of energy consumption during the operation of the building.

Within the scope of INSITER, the CARTIF-III building in Valladolid in Spain is in the maintenance and operational phases of the building's lifecycle. Therefore, data from this building is used to demonstrate the usage of monitoring tools. In this case, the tool is based on the commercial TAC-Vista solution from Schneider Electric, which implements the sensor network where data are measured. However, CARTIF (a private and non-profit technology center) has developed its own data visualization tools and database to keep historical records and provide a graphical interface where the behaviour of the building may be extracted.

Figure 90 Monitoring of the Cartif building with Energy Consumption for lighting and Heat Pump

Technical building services and systems of the CARTIF-III building can be visualized within the applied monitoring platform. The two examples are shown in the next figures, illustrating the Air Handling Unit and biomass energy production. However, there are other systems which are fully monitored as follows:

- PV – generated electricity and delivered energy are the main parameters.
- Biomass – Status of the boiler, temperatures, valves and inertia tanks are metered.
- Geothermal – Heat pumps statues, temperatures and production.
- AHUs (air handling units)– Status of the fans, temperatures and pressures are measured.
- Solar thermal – Generated energy, temperature of the water and the storage tanks are its main elements.
- Radiant floor – Status of the distribution valves and temperatures.
- Lighting – Status of the lamps and lux levels.
- Electricity consumption per system (e.g. electricity necessary for the heat pumps).

The monitoring of the installations helps to identify deviations in performance of the installations or even the building envelope.

The set values in the design phase together with the sensitivity analyses, compared to the actual situation gives valuable input for the energy efficiency of the building.

inspection&FolderCTID=0x0120005C21D6ACB1F3E149B50A9C7B37A2F7A6&View=%7B0405C740-3FC5-4290-95F2-9C3828FCEC6C%7D

Example of Building process step 7

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
7	Self-inspection during construction / refurbishment / maintenance process	Perform self-inspection during construction / refurbishment / maintenance process	Understand critical deviation and know what to do: start again, repair or talk with the building site manager how to solve the problem
			Control the quality of the façade with thermographic camera; communicate with the building site manager asap if the deviations are critical

Sub-task name(s)	Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competences)
7.1	Construction worker	How to work with the AR device to detect critical deviations in the façade with prefabricated panels	Which deviation or leakage is not correct? Which deviation or leakage is critical for the energy performance of the façade?	Understand critical deviation and know what to do: start again, repair or talk with the building site manager how to solve the problem
7.2	Inspector	How to use a thermographic camera, how to registrate thermographic images of agreed areas, how to identify thermal bridges, critical joints in the facade	Which deviation or leakage is critical for the energy performance of the façade?	Control the quality of the façade with thermographic camera; communicate with the building site manager asap if the deviations are critical

3.7.3 Conclusion

Figure 91 Self-inspection within the INSITER 8-step model, including the output to the next INSITER step

Within this step of the INSITER 8 [...] e inspection tool [...] n order for construction workers to be able to inspect on[...]er's work, and the [...] and act upon deviations or defects at an earlier stage in the [...] The innovations [...] regards to this are twofold: on one hand it has developed an [...] o capture this pro[...] en more important, it proposes a shift in the process of construction by placing an emphasis on this activity, which is far from common in contemporary construction.

Additionally, in one of INSITER's demonstration cases, the CARTIF-III building, a graphical interface and the capture of historic data have been developed within the scope of INSITER.

Category Intervention	Refurbishment
Critical EeB Component	Mechanical ventilation
INSITER Methodology	☐ Step 1: Mapping
	☐ Step 2: Checking of ordered components
	☐ Step 3: BIM for on-site construction
	☐ Step 4: BIM-based Augmented Reality

	☐ Step 5: Visual clash detection during construction
	☐ Step 6: Self-instruction
	☒ **Step 7: Self-inspection**
	☐ Step 8: Final check
Intervention description	*Main critical points:* • Air leakage due to ventilation (tightness of the duct system) *Key activities:* • Fill-in the checklist; • Take at least one picture for each question of the checklist; • Add notes when needed and report your findings.
Technical data and information	• Example_Common errors • Example_Self-inspection activities

3.8 Step 8: Final check

Figure 92 Final checks within the INSITER 8-step model

The final step in the INSITER 8-step model functions as a monitoring and verification mechanism for the on-site performance; it aims to provide a holistic overview of the activities of the workforce. The key in such an overview is condensing data; throughout the INSITER 8-step model an abundance of data is created, which is difficult to oversee without filtering and weighing it.

Figure 93 The INSITER collaboration platform offers in the eighth step (Final check) access to the RE Dashboard.

Use-case

The final checks are envisioned to be used by construction supervisors, site managers and/or BIM-managers. This wide range of professions that are foreseen to be using the tools provided in this step stems from the fact that they can be used both in off- as well as on-site situations. An on-site application could be to monitor the amount and severity of the defects and deviations as a result of self-inspection by construction workers. Additionally, off-site applications could include finding the solution to a clash issue during the clash detection step within the INSITER 8-step model.

Such applications in itself are not new. However, the use of these applications within the construction process itself, as a live feedback tool for project or site managers is a novelty developed in INSITER.

INSITER added value

RE Dashboard

RE Dashboard is a decision support framework developed by DMO, able to visualize the performance of processes related to the built environment through the calculation or determination and display of Key Performance Indicators (KPI's), Performance Indicators or Indicators. The key functionality of RE Dashboard in INSITER is to integrate and/or aggregate monitored data and scale it to an ordinal value, after which it is displayed in user-friendly dashboard elements such as gauges.

By checking the dashboard frequently, the project manager is able to monitor the process real-time, and to take decisions in time when needed. This highlights the importance of monitoring over time to calculate or determine KPIs and thus allow decision-making. RE Dashboard contains the following functionalities:

- **KPI calculation or determination**

  As eluded to before, the foundation for a dashboard is the calculation or determination of KPI's. Within INSITER, KPI's are defined both for the construction as well as for the commissioning phases: for example during the commissioning and maintenance or operational phase of the buildings the heat and cold distribution are monitored and captured in a KPI. During the construction phase KPIs indicating the quality of work are included in the dashboard to help the on-site team to identify the errors according to the guidelines.

Energy

In the case of the commissioning and post-commissioning, similar to monitoring, CARTIF-III is already providing KPIs for the energy performance as illustrated in the figure, where annual values are shown for delivered energy (EDEL), per system: thermal (TH), electrical (EL), geothermal heat pump (GHP) and biomass (BIO).

-

Figure 94 Energy KPIs for the CARTIF-III demonstration case

Displaying dashboards

After KPI's have been calculated or determined they are displayed in a dashboard through dashboard elements.

Examples of such dashboard elements are traffic lights, gauges, spider diagrams and trend charts. Dashboard can be viewed through the RE Suite on a PC, or through a web browser allowing for mobile and on-site access.

Figure 72: Energy Efficiency (EE) dashboard for usage during the commissioning phase

Setting dashboard alarms

A crucial functionality for effectively monitoring the KPI's displayed in a dashboard is being able to set alarms. Minimum and maximum thresholds can be defined as triggers for raising an alarm, as well as the definition of an action to be undertaken when the alarm goes off, such as sending an email to the site supervisor. This functionality alleviates the absolute need for the site supervisor to consistently periodically check the dashboard, as he or she can trust that once an indicator reaches unacceptable or attention-requiring values an action will be automatically performed.

Figure 95: Setting threshold values and dashboard alarms

3.8.1 Design Coordination System (DCS)

The Design Coordination System (DCS) is a software application to access the results of a clash detection performed with the DCA plugin, as described in step 5. It has been developed in conjunction with the Design Coordination Analyser to serve as the front-end for coordination. This tool will be used off-site and is intended to be used by BIM-Managers and all design related personnel to optimize the design, find solutions for detected issues and clarify any issues before forwarding the solution to on-site personnel. All issues, which have been coordinated to be solved on site, can be forwarded via the Clash Cube Generator to the site team.

The User Interface is divided into six main areas, and consists of the following elements:

- Interference Information:

  Provides relevant information about the selected clash (e.g. involved trades)

- Interference List:

  List of clashes, which are currently filtered.

- Overview/Original View:

  Shows a preview image of the specific viewpoint alternative.

- Coordination Information:

  Area to enter specific coordination tasks, due dates, responsible person.

- Filter:

  Several filter options to adjust the list of currently shown interferences.

- Navigation Toolbar:

  Navigation tools to navigate through the 3D model.

Figure 96 User interface of the Design Coordination System (DCS)

Beside the coordination window, there is an additional analysis window. This dashboard provides an overview of the current project situation regarding the performed clash detection.

It is also possible to focus on specific items by just clicking on the specific information.

97Analysis of the performed clash detections

Three different reporting options allow the user to export their coordination information to provide it to responsible partners:

- **Management Report**

  Provides the current project information as shown in the dashboard.

- **Meeting report**

  Gives a summary of the selected meeting (Including detailed information about the clashes coordinated in that meeting)

- **Individual Selection**

  Same as Meeting report, but with individually selected clashes

Figure 98 Three report types

3.8.2 **User manuals Step 8 in INSITER:**

https://cmis.demobv.nl/insiter/Manuals/Forms/AllItems.aspx?RootFolder=%2Finsiter%2FManuals%2F8%2E%20Decisio n%20making&FolderCTID=0x0120005C21D6ACB1F3E149B50A9C7B37A2F7A6&View=%7B0405C740-3FC5-4290- 95F2-9C3828FCEC6C%7D

Example of Building process step 8

Qualifications; Example prefabricated Façade panels

INSITER step	INSITER description	Task name	
8	Self-inspection and self-instruction during pre-commissioning, commissioning and project delivery	Perform self-inspection and self-instruction during pre-commissioning, commissioning and project delivery	Control the delivered documents and check the documents and façade unselective, show unselective recent thermographic images to the commissioner
			Control the delivered documents and recent thermographic images

Sub-task name(s)	Actors	K1: List of what to know (knowledge)	K2: List of what to understand (skill)	K3: List of what to be able to do (competences)
8.1	Building site manager	Critical joints in the façade, how to check the delivered documents about self-inspection of the facade	Which deviation or leakage is critical for the energy performance of the facade?	Control the delivered documents and check the documents and façade unselective, show unselective recent thermographic images to the commissioner
8.2	Commissioner	Technical specifications of the façade, critical joints in the façade, how to check the delivered documents	Which deviation or leakage is critical for the energy performance of the façade?	Control the delivered documents and recent thermographic image

3.8.3 Conclusion

In the eighth and final step in the INSITER 8-step model two tools have been provided which help the on-site team with keeping track of the progress and quality of the construction process. Both tools are characterized by the integration and aggregation of data, after which it is presented in a user-friendly and easily understandable way. However, the target audience of both tools differs; RE Dashboard is intended to be used directly on-site by site or project managers, while the Design Coordination System (DCS) is used off-site, from where the results are transferred to the on-site team through another INSITER-developed application, the Clash Cube Creator.

4 Interoperability tools INSITER

Interoperability is a key aspect in all tools and it is defined as a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, without any restriction. According to this definition, there are two main aspects to deal with.

The first one is to establish well-known interfaces between all the elements that need to exchange data. Secondly, the use of standards helps to achieve the interoperability. Within INSITER, the framework has been set-up in order to ensure interoperability. Figure XX represents the framework and how the elements are interconnected. The framework allows the integration of the tools with the acquisition systems and data repositories and, thus, creates an environment where the tools exchange information with the servers. Under the concept of this framework the INSITER collaboration platform is developed to provide a single access point to the tools of the application layer.

Figure 99 The collaboration platform and the single access to the INSITER tools

From the acquisition layer, equipment is able to collect data in multiple and diverse formats. That is the reason an INSITER-DLL, a Revit library, has been developed with the aim of accommodating data from the images to IFC based data in Revit. The exception lies in the sensor whose adaptation into IFC is directly done in the database itself. The BIM layer is IFC-compliant being composed of the BIM-Server containing the BIM models from the buildings and the information from the acquisition systems related to the building. Moreover, the database is IFC-compliant as already described and it complements the static data from the BIM and the SharePoint servers to store files, data-sheets and any complementary information. Once all the information is stored in the IFC format, the application layer, where the services are deployed, is able to make use of the data by simply combining the information from different sources. These three different sources or components that together form the INSITER framework will now each be discussed in more detail.

Figure 100 Interoperability framework

4.1 Open Source BIM server

The Open source BIM server is used as the main storage solution for the BIM / IFC models. The solution is built on top of several well-tested and widely used open source solutions. In the context of a framework it is a perfect solution as it is extendable, accessible and any alternative that works as a server is much more expensive.

The BIM server is a solution for, among other functionality, storing and accessing BIM-files. It is free, fast, stable and being actively developed on. Within INSITER the existing API is used to connect to the database via C++, C# (.NET) and JAVA. The experience with this component of the INSITER framework has been positive; it has proven to be a stable and well-performing solution for storing and accessing BIM-models.

The main functionality of the server used within INSITER is upload, download and versioning the latest BIM models. Although there are many more extra functionalities offered by the open source BIM server and its database, the solutions within INSITER have grown to having them embedded inside their applications itself, giving more control and flexibility within the developed and utilized applications. As there are several mature IFC toolboxes and they work for all available IFC versions the overload of implementing IFC within an application is less complex than it might seem at the beginning.

4.2 Microsoft SharePoint

Microsoft SharePoint is a mature, widely used and scalable solution for file storage and versioning. As described in the INSITER toolset, Microsoft is the backbone for the INSITER collaboration platform. It is within this platform that all data needed for or exchanged by INSITER tools, demonstrators within the 8-step methodology as well as further documents are shared and are available.

The structuring of these documents is done through a 2-layer approach. First, documents are split by demonstration case. Then, a second layer of decomposition is added according to the steps in the INSITER 8-step model. This ensures the logical storage of documents and data.

In the light of interoperability, the SharePoint environment has been extended by a CMIS (Content Management Interoperability Services) interface. CMIS is an interoperability standard that facilitates the communication between content management systems and the tools that access them. Several applications including the RE Suite have implemented CMIS to adapt the application interface towards the available structure in SharePoint.

It is this combination of human, through the INSITER collaboration platform front-end and GUI, and machine, through the native or CMIS interfaces, readability that ensures the accessibility and use of this component of the INSITER framework.

4.3 PostgreSQL database

Where the previous databases are mainly used for storing files, albeit with some meta-information about the documents and their interrelation, the PostgreSQL component of the INSITER framework has a strong focus on both meta and real-time data, not stored within files or required as meta-data directly.

After much debate about the type of database needed for this kind of data, the choice was made for a SQL database over an object based database. Already at the beginning of the INSITER project the need for a database able to store meta and real-time data was clear. However, the exact form in which such a database remained the subject of discussion for a long time, also influenced by the guidelines and recommendations outlined.

The current PostgreSQL database is accompanied with a dedicated library (DLL) developed by CARTIF that facilitates access to this database and its internal structure in an easier manner.

The content in the PostgreSQL database also contains references towards existing documents. The vehicle for relating data from the PostgreSQL database to other (BIM-)objects is through their globally unique identifier (GUID).

5 Guidelines 8-steps heatpump

INSITER Guidelines Explorer

Project Type	Critical Component	INSITER Step
No selection ▼	6. Heat pump system ▼	No selection ▼

1. Existing | 6. Heat pump system | 1. Mapping

Main critical points:

- The condition of the floor of the mounting place;
- The structural condition of the wall and ceiling to hang/mount the piping system (related to the heat pump system);
- The possibility to transport, lift and storage the heat pump system within the structural limitations of the building (if the case).

Key activities:

- Check the building conditions includir device.
- Map actual conditions in relation to:
1. the structural conditions in relation to
2. the structural and mechanical conditio
3. the structural and technical conditions

1. Existing | 6. Heat pump system | 2. Checking of components

Main critical points:

- The correctness of heat pump units and components delivered on-site;
- The presence and the level of damage from transport;
- The handling and storage of components and building materials on-site.

Key activities:

- Scan an attached QR or RFID code with an iPad on the packaging;
- Retrieve the specifications of each component linked to each component's ID;
- Check for the right quality certificates if available;
- Retrieve the site storage plan;
- Check whether these are the correct ones as specified in the BIM model and the specifications;
- Store the heat pump according to the manufacturer instructions;
- Follow steps in Checklist Pre-start Checkout reference material attached.

Special attention:

- Check if any materials or components have been damaged from transport;
- The heat pump is free of damages and corrosion;
- All components and pipes are not-moved (check manufacturer instruction);
- Presence of the interior and exterior nameplates;
- If information on the nameplates corresponds to the order;
- If information on the nameplates corresponds to the manufacturer information.

1

Main critical points:

- Completely and accurately follow the building design;
- Having access through BIM to all parts and relevant technical details;
- Having available the latest versions of the design details to be executed;
- Avoid decreasing the overall building quality caused by ad-hoc solutions.

Key activities:

- Open BIM by using the scanned QR or RFID code from step 2.
- The highlighted part corresponds to the exact location of each element to be installed;
- Use the BIM model on the BIM viewer to observe how the heat pump is modelled;
- Use the component BIM model (if available) of the heat pump and other related systems (piping, pumps...) to check the technical details;
- Note down any remarks, questions or doubts on the observation panel.

![INSITER - INTUITIVE SELF-INSPECTION TECHNIQUES]

1. Existing | 6. Heat pump system | 4. BIM-based augmented reality

Main critical points:

- Completely and accurately follow the building design;
- Detailing to be followed.

Key activities:

- You can use here one of the BIM-based AR solutions for INSITER to visualize:

1. BIM and 3D objects on-site environment;

2. Self-instruction data with process sequences;

3. 3D animations;

4. Technical details;

5. Workflows;

6. Thermal images, acoustic measurements.

- You can project on the real environment the heat pump system to be installed so that you can check visually the correct location and position;
- You can retrieve and project through BIM the above information (2-6);
- Please use this material as a reference and try to understand your tasks and the expected result;
- Note down any remarks on the observation panel, questions or doubts.

Special attention:

- Be sure that all hardware and cameras are calibrated;
- Be sure that AR markers are placed and will remain in the same position as long as you are using the AR apps;
- AR markers should be visible around your working area;
- Use the markers for the initialization of the applications and your navigation;
- If AR markers are combined with marker-less tracking make sure that supplementary markers are introduced to the screen.

1. Existing | 6. Heat pump system | 5. Clash detection during construction

Main critical points:

- Clashes correspond to potential inconsistencies between design and realization, such as:
1. Elements not given the required spatial or geometric tolerances;
2. Elements that its buffer zone is breached.

Key activities:

- You can use here one of the BIM-based AR solutions for INSITER;
- Test AR on-site for visual comparisons between BIM model and realization of Heat pump components installations based on visualisation of virtual clashes (super-imposed).
- Refer to Step 4 whenever you have doubts about how to use the AR apps;
- Note down remarks on the observation panel.

Special attention:

- Mounting/levelling errors and inconsistencies;
- The suitability of the building structure for the HP system (regarding weight);
- The suitability of the mounting place for the HP system (regarding place);
- Check the levelling of the mounting place.

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1. Existing | 6. Heat pump system | 6. Self-instruction

Main critical points:

- Accurately follow the manufacturer's assembly/installation manual;
- Collaboration between mounting team members (mechanical, technical).

Key activities:

(mechanical):

- Start the foundation steps following the manufacturer instruction;
- Prepare the mounting area considering clearances issues according to manufacturer instructions;
- Start unpacking procedures considering rigging and lifting issues;
- Start mounting procedures considering levelling and isolation instructions provided by the manufacturer:
1. Mounting the evaporator water piping;
2. Condenser Water Piping
3. System Configuration

(electrical):

- Start reading general recommendations provided by the manufacturer
- Start installing:
1. Installer-supplied component;
2. Interconnecting wiring;
3. Communication interface.

1. Existing | 6. Heat pump system | 7. Self-inspection

Main critical points:

- Acoustic issues;
- Hazardous voltage issues;
- Pressure issues;
- Configuration issues.

Key activities:

- Fill-in the *checklist*;
- Take at least one picture for each question of the *checklist*;
- Add notes when needed and report your findings.

Files

    Checklist Pre Start Checkout

    Example Checklist

    Self-inspection checklist

---

1. Existing | 6. Heat pump system | 8. Final Checks

Main critical points:

- Having access to all data and information from the previous steps.

Key activities:

- Make sure you have all your findings for steps 1-7 (images, notes, remarks);
- Open the observation panel and note down your final remarks.

  In these please include:

  1. deviations from initial planning;

  2. deviations from designs;

  3. any problem you have faced.

- In the observation panel please answer the following questions:

  1. To what extent have the tools contributed to properly performing the dedicated activity?

  2. To what extent have the tools contributed to avoiding mistakes?

  3. How many mistakes have been avoided by using the tools?

- Sign and finalize your report.

5.1 Guidelines for new components

New components can be implemented in INSITER's quality assurance methodology. The requirements for the following

INSITER steps are important to consider.

1. (Step 2) Using QR the component must be identifiable. In the Sharepoint database, at least the following information must be present:
    a. Model number; a general number for the specific product. Included are quality certificates that are related to that specific product.
    b. Part number; a specific and unique number to the model. Includes are technical specifications of the specific model.
    c. Serial number; a unique identifier number assigned incrementally or sequentially to a single part or item. Included are (if applies) manufacturers test certificates and results for the specific item.
2. (Step 3) The component must be modelled in the design building information model (BIM).
3. (Step 6) For mounting the component, detailed instructions must be available. These instructions can be pdf-documents or text in xml language. It is also possible to have complementary video instructions or even an IFC instruction model (visualization of the mounting process).
4. (Step 7) For self-inspection purposes, specific product related protocols are needed. The protocols need to be related to common errors and for INSITER purposed also to the energy efficiency and indoor environmental quality of the building. For example, if incorrect connections to the component can lead to leakages, a correct connection to other components must be inspected (e.g. "is the connection to other component sealed with a rubber sealing ring?"). The protocols need to be administered with:
    o Sequence number;
    o Description of the inspection; preferably a question that can be answered with 'yes' or 'no' (or n.a.). Also possible to have an open question to be filled in with, for example, a (measured) value.
    o Answerable options (yes/no/n.a.) or an open field for textual input.

5.1.1 Guideline tables

For each step of the INSITER methodology, a table can be filled in. The tables (8 in total) present the objectives, actions, notes and necessities of a (new) component to be functional within the guideline inspection app. The table is organized in two main parts: the "intervention description" and the "technical data and information".

The "Intervention description" presents:

*   which are, in overall, the "Main critical points" of the step itself (objectives). The manufacturer describes what aspects are critical for correct positioning, mounting, installation, completing and functioning of the component.

*   which are the "Key activities" that the worker has to do within the step; The actions need to respond to the objectives, in order to check or secure correct operation.

*   which are the situations or points on which the worker has to put "Special attention". For example, if any special action or instrument is needed to complete the task.

"Technical data and information" contains all the useful documentation that must be available for the worker.

• Critical EeB Component	• …
• INSITER Methodology	• ☐ • Step 1: Mapping
	• ☐ • Step 2: Checking of ordered components
	• ☐ • Step 3: BIM for on-site construction
	• ☐ • Step 4: BIM-based Augmented Reality
	• ☐ • Step 5: Visual clash detection during construction
	• ☐ • Step 6: Self-instruction
	• ☐ • Step 7: Self-inspection

	• ☐	• Step 8: Final check

•
• Intervention description
	5.1.1.1 Main critical points:
	
	    • ...
	
	5.1.1.2 Key activities:
	
	    • …
	
	5.1.1.3 Special attention:
	
	    • ...
	
	•	

• • Technical data and information	• • ... •	

Table for the 8-step guideline inspection

6 Simulation based inspection & self-inspection

6.1 Self-inspection and the complexity of HVAC/ MEP systems

Buildings we realize are getting better, smarter, and more connected. Current buildings go beyond offering only basic services. Buildings have to meet high levels of aesthetic requirements, user needs and expectations and to meet the building code (regulations). All of this have to be done considering high levels of sustainability and return on investment.

6.2 Factors influencing building quality

There are many factors influencing the total (actual) building quality and energy performance (see Figure 79). The most important factors are:

- the building envelop including facades, windows, walls etc.;
- the HVAC/MEP systems including heating & cooling generation, distribution and supply;
- use & user profile including building occupancy, activities to be performed in the building, number and type of appliances etc.; and
- weather conditions

Each of these factors can positively or negatively influence the total quality of the building or the energy performance. Besides, building and HVAC/MEP can strongly influence each other in terms of energy efficiency. Here below some examples are listed:

- Deviations in quality of building elements (e.g. lower R_c-value or higher air infiltration) may cause higher energy demand and therefore higher energy consumption by the heat pump.
- Performance deviations in heat pump system and the related distribution circuit result in insufficient delivery of space heating causing lower thermal comfort, dissatisfaction and complaints of the building users.
- It also results in higher energy consumption by the heating system
- Deviations in ventilation air supply may cause undesired deviations in indoor temperature causing higher demand for heating of for cooling and therefore higher energy consumption.

Figure 101: illustration of factors influencing the total quality performance of a commercial building

6.3 Levels of self-inspection

To ensure that the building properly performs and sufficiently provides the required levels of space heating or cooling all building elements and HVAC/MEP systems have to properly work and interact with each other. To achieve that, all HVAC/MEP have to go through well-developed inspection and quality control processes. The INSITER methodology is based on a bottom-up approach. It starts at the component level and ends at the system/building level.

The figure below shows a adjusted version of the inspection levels according to the INSITER methodology.

Figure 102 levels and types of inspections according to the INSITER's methodology

In Table 1 these levels have been explained in accordance to the commissioning levels as presented in Figure below. In the following sections, the several levels of inspections will be discussed. To understand those inspection levels and complexity of the higher level of inspection, the heat pump system will be considered as an example.

Figure 103 the commissioning services according to the DWA business

Inspection level	Inspection aim	Action and tolerance
Damages and pollution I & II	**Quantity** check: visual inspection for quantity and damage	Damaged or polluted components should be replaced if repair or cleaning is not possible.
Product identification I & II	**Quality** check: comparison to the specification in BIM	In case of deviation (negatively influencing the performance), the component should be rejected if performance specifications are lower than designed.
Self-inspection protocols I & II	**Functionality** check: comparison to the specifications in BIM	In case of performance deviation, the component should be replaced if performance specifications are lower than designed. In case of setting deviation, the component should be fixed.
Measurement and calculation	**Performance** check: comparison to the design specifications and expected performance output	Performance deviations should be evaluated according to agreed values and tolerances.
Monitoring	**Performance** check: in real use conditions (weather and occupancy for a long period (one year after delivery)	Performance deviations should be evaluated according to agreed values and tolerances.

Table 1: levels of inspections in relation to commissioning

6.3.1 Inspection at the component level

The most components of the HVAC/MEP systems are mass-productions products. Valves, pipes, filters, sensors and pumps are mass produced components. The production process of these components is further developed. A lot of inspection and quality control work takes place in the factory ensuring high levels of certainty of performance. It is clear that rejected components in the factory will not be used.

Self-inspection of a component, as a stand-alone part, is perhaps the most well-understood form of inspection. Besides

to the factory acceptance test, on-site self-inspections will be performed including product identification and damages/pollution inspection. These first and second levels of self-inspection ensure that the component is capable to perform in the right way. This is of course a basic requirement for well-functioning of the whole system.

The third level of self-inspection ensures that components have been properly mounted having the right settings (e.g.

Figure 104visualisation of individual components as part of a heating system

opening position of a valve, flow direction of a valve). The third inspection level ensures also, to accepted levels, that the components, in this example as a part of the distribution circuit, will properly interact with the other components. This is also a basic requirement for well-functioning of the whole system.

6.3.2 Inspection at the subsystem level

A subsystem is a set of interacting and interdependent components, forming a system itself, but also acting as a component of a larger system. Examples of subsystems are heat pumps, hot water storage and distribution circuit as parts of a heating system. Subsystems are traditionally fully produced in the factory and installed on-site (heat pump). Some subsystems or their components like piping and duct systems can be (partly) prefabricated. Figure 83 shows some subsystems of a heating system of a commercial building.

Figure 105examples of subsystems of a heating system in a commercial building

Self-inspecting of subsystems covers:

- Quantity self-inspection: product identification ensuring the right product is mounted;
- Quality self-inspection: product is not damaged; and
- Functionality self-inspection as part of the site acceptance test (SAT).

The self-inspection at the functionality level depends on the way subsystems have been produced. Mass-produced subsystems such as heat pumps are inspected in the factory and installed on-site by an expert team including experts from the manufacturer, a mechanical engineer and an electrical engineer. These systems get also inspected by the expert team. The result of the first inspection is a factory acceptance test FAT and the result of the second inspection is a site acceptance test SAT. Reports of both tests are delivered and saved. However both tests are done due to the factory conditions and to the design parameters and not to the actual use conditions of the building.

Figure 106several inspection processes for several levels of components and subsystems

The most interesting elements of the actual inspection of such subsystems is if these systems will mutually interact in the right way and ensure the delivery of the requested performance. This is a process that takes place after the building delivery and covers long period of monitoring.

In relation to performance measurements, construction and HVAC/MEP workers have to have information and tools to support their decision making process during the self-inspection process. They have to be able to decide if measured performances (and possible related deviations) could be accepted or not. Also to decide on the impact of that deviation on the actual building performance. Following deviation tolerance percentages doesn't respond to the actual situation as buildings differ in almost all specifications of buildings envelop and HVAC/MEP systems. This means that performance deviations in a specific element/component could have different impact on the actual building performance. To overcome this challenge, we introduce a new approach in the next Chapter.

6.3.3 Inspection at the system and building level

Self-inspection by workers at the system level and the building level is perhaps the most complicated stage of the quality control process. After self-inspecting all components and subsystems including quantity, quality and functionality issues, workers have to ensure that the components, subsystems and systems will, in its entirety, properly perform according to the design and the building demand. This also means that the brain of the building, the Building Management System, will properly control the HVAC/MEP systems in actual situations. There are two important challenges for self-inspecting at this stage. First, the INSITER project is about the self-inspection process during the construction stage as the workers are installing/mounting the components and subsystems. In that stage the HVAC/MEP systems are not completed yet and therefore self-inspection of performance at this level is difficult and is limited to the connection, joint, ductwork etc. Second, as the building is not completed and not occupied yet, there is e.g. no heating, cooling or ventilation demand from the building. It this case, HVAC/MEP cannot be inspected in real conditions. For this reason, real conditions should be mimicked by creating e.g. a virtual situation having building users and heating demand. The real performance inspection for the whole building and its HVAC/MEP systems is in the use phase. In the use phase, real sensor data and meter measurements are used analyse building performance (using performance monitoring techniques like Simaxx). In the current practice, the Commissioning authority is in charge for this inspection stage. It is for this reason outside the scope of the INSITER project, but relevant because of the self-inspection step in INSITER. However, in the next Chapter, we see some scenario based and monitoring techniques in the new approach.

6.4 Total building quality and related KPI's

The following set of KPI's is covering the most important quality issues of building: Energy Efficiency and Indoor Environment Quality, see Figure below.

KPI's related to Energy Efficiency has been grouped in four sub-groups covering the whole energy process: generation, transfer, distribution and storage. For the Indoor Environment Quality, four KPI sub-groups have been defined including: indoor air quality, Acoustic Comfort, Visual Comfort and Thermal Comfort. We defined very specific measurement fields that contribute to the whole building quality.

Although total quality is top-down defined, performance measurements and self-inspection processes will be discussed bottom-up. Figure below will be adjusted for each studied HVAC/MEP system indicating available and executable performance measurements.

Figure 107 overview of used KPI's for HVAC/MEP systems

7 A new diagnosis approach

The INSITER approach focuses on transferring the inspection responsibilities to construction and HVAC/MEP workers during the construction phase creating a so-called self-inspection process. The new INSITER methodology should at the same time ensure that the self-inspection is going through a smooth process without adding extra work load to the workers. Such a transfer should attentively be organized and prepared. Workers will get equipped with well-structured process, measurement devices and decision making tools/information to support taking the right decision. All this is going through a BIM process.

In the previous sections, the self-inspection methodology is discussed on the several levels of the HVAC/MEP systems introducing some difficulties of self-inspection in relation to current practices. This Chapter, is introducing a new approach to support the self-inspection at the functionality level for systems and subsystems.

7.1 The role of simulation techniques

Simulation techniques, simulation software or building performance simulations are software to predict and evaluate one or more performance aspects of a building and its related HVAC/MEP systems. Simulation software aims at creating a virtual model of the building that is sufficiently accurate to form a useful representation of the actual building. Current simulation software covers a long list of building performance aspects including:

- *Indoor climate*: ambient air temperature, relative humidity, solar radiation and comfort levels.
- *Energy*: internal energy gains, energy consumption and generation of renewable energy.
- *Distribution circuit*: hydraulic installation designs.

The input for simulation software differs according to the simulated performance aspect. Generally speaking, detailed geometric and HVAC/MEP information are the input for simulation. The simulation software in relation to the purpose of the INSITER project includes VABI Elements, TRNSYS and Hysopt. For practical issues, we only focus on VABI Elements in the next sections to explain the new approach. To be clear the most simulation software can be used for the new approach.

VABI-elements is a dynamic building performance simulation tool to simulate the buildings performance in which the installations are coupled to the building. Besides hydraulic systems, VABI-elements contains modules for ventilation, cost, and planning. A connection to BIM is available where the building geometry is imported using the IFC file. Simulations have a low level of detail and can be performed in an early design stage, for example, when the installation concept is known or developed. The building is represented by a three-dimensional model of the building geometry including materials and their properties. Installation concepts are selected and control strategy must be entered. When performing a simulation for a building all building and HVAC/MEP details will be used to simulate the performance of the building. Changing one or more details or parameters will result in new performance output. The new approach will based on this functionality.

Imagine that we adjust the U-value of an external wall mimicking an inspected deviation in the building façade. Or adjusting the COP of a heat pump mimicking lower delivered performance during the use of the building. Re-simulating the building will perhaps result in a new performance level: higher energy consumption levels or lower levels or higher levels of CO_2 production. The difference between the two levels of performance is the performance deviation caused by

the inspected deviation. Repeating this work for several deviations levels can result in a graph presenting the relationship between measured deviation and simulated performance deviation. Such a graph can be used by workers to understand the impact of measured deviations and support the decision making process during a self-inspection process. In some cases, there is no need for complicated simulations as simplified calculations can help creating such a graph. Figure below illustrates the use of simulation software in generating graphs of performance deviations. Hereafter we will call it a sensitivity analysis.

Figure 108 illustration of the role of simulation software in the sensitivity analysis

In the next sections the new approach will be presented and discussed as a part of the whole self-inspection methodology.

7.2 Simulation based self-inspection

Self-inspection by workers at the functionality and the performance level requires that workers can understand measured deviations and can be able to make the right decision about accepting or rejecting the inspected subsystem in case of deviation. Especially the impact of a measured performance deviation on a KPI or total building quality is a hard issue. The following steps present the simulation based self-inspection approach that fulfil the needs of the workers during the self-inspection process. In order to better follow the approach, examples related to energy consumption as KPI will be used.

1   Starting point; understanding building performance and major influencing systems

Energy efficiency of buildings depends on several factors including building envelop (design, orientation, occupation, etc.) and HVAC/MEP systems. It means that different buildings have different energy consumption patterns. In other words there are different shares of energy consumptions for space heating, cooling, lighting etc. (see Figure below).

Figure 109 understanding energy consumption pattern by energy simulation

Figure below shows energy consumption patterns of two different commercial buildings. The building at left has a bigger energy share for lighting in relation to cooling and heating. This is because of the building year, use of traditional lighting systems. The building at right shows a different energy consumption pattern having a bigger share of energy consumption for space heating in relation to lighting. Understanding this kind of energy consumption patterns can help building designers and quality inspectors to pay extra attention to subsystems and systems that directly or indirectly influence energy efficiency.

Figure 110 comparison of energy consumption patterns between two different commercial buildings

2   Re-prioritizing lists of common errors and critical components

In INSITER there are lists available of common errors and critical components for building elements and HVAC/MEP systems. In those lists, common errors and critical components had the same priority in the self-inspection

process. However, based on Step 1, common errors and critical components may get different priorities according to their impact on the examined KPI. For example, additional attention can be paid on lighting systems if simulations reveal that lighting the major energy consuming systems in the building. However, this doesn't mean that other systems are less important.

3   Setting up a simulation strategy

In this step we first select the KPI's in question. Based on Step 2, we indicate which measurements should be performed during the self-inspection process. More specific, to determine which input and performance output is related to that measurements. At the end of this step, we create a list of measurements (performance output) and related input parameters to be simulated next step; see Figure below. Examples of high prioritized measurements are the COP of a heat pump or the efficiency of a ventilation system.

Figure 111illustration of creating measurements to be simulated

Figure 112illustration of a threshold based on a simulation approach

4   Simulating performance deviations

In Step 3 we created lists of prioritized measurements to be performed during the self-inspection processes. The values of these measurements are actual performance of the specific component or subsystem. If all installing and mounting processes went well, this actual performance should be equal to the design performance; **as-designed = as-built**. In the case of performance deviation, workers have to quantify the impact of performance deviation on the related KPI and finally on the building quality. They need information (graphs) about the relationship between measurement deviations and performance deviations. By using that, they are able to properly evaluate the deviation and taking the right decision: accepting the deviation or rejecting it. For this purpose, performance deviation graphs should be created using the simulation software: a kind of simulated performance deviation. Figure 90 illustrates a performance deviation graph.

Let's take the heat pump as an example. We know that heat pump is a crucial part in the heating system. The Coefficient of Performance (COP) of the heat pump is a good indicator for the performance of the heat pump. In the construction phase and right during the installation of the heat pump it is very hard to quantify the impact of possible COP deviation on the Energy Efficiency as a whole indicator for building quality. In this case, we are going to measure the COP of the heat pump. We will use the simulation software to create a graph presenting the relations between the COP deviation and the total energy consumption.

Figure 113 graph illustrating the relationship between measured performance and simulated impact on performance

5   *Determination of thresholds*

After simulating the relationship between measured performance and its impact on actual KPI performance, it is essential to agree on the boundaries in between deviations are accepted: ***thresholds***. Manufacturers prescribe maximal accepted performance deviations (thresholds) for their products (components or subsystems). However, those thresholds consider optimal test conditions (usual factory conditions). Performance deviations below prescribed thresholds can have large impact on actual performance. Especially in the case that several, may be aggregated, performance deviations can simultaneously take place. For this reason, building designers together with commissioning experts have to agree and indicate the boundaries in between performance deviations could be accepted by the workers during a self-inspection process. Figure below shows that, for example, a performance deviation of 6% is the maximum to be accepted as it results in 5% deviation in the Energy Efficiency (EE).

This approach is applied in a heat pump system in considering the COP as a measured performance for a real building.

7.3 Integration in the INSITER methodology

The presented approach in Section 2.5 adds new level to the self-inspection process of the INSITER methodology, see

Figure 114Summery of test and measurements, based on the approach

Figure below. Especially for mass-production components and subsystems, this approach is complementary to the factory acceptance tests performed by the manufacturers off-site. The new approach considering a functional test in, to somewhat, actual test conditions. Together with the quantity and quality check, see Figure below, performance gap between design and realisation, as main goal of the INSITER project, can be ensured.

Figure 115several levels and types of inspections in the different phase of construction

Workers benefit, during self-inspection processes on-site, from already created lists of common errors and critical components. These lists are based on experience of the consortium partners. Following the new diagnosis approach, the mentioned lists get better and more relevant as errors and components could be prioritized according to KPI's. The preparation for this diagnosis approach starts in the design stage using simulation software (in not complicated cases, calculations can be substitute simulation software).

To summarize, the INSITER methodology includes checks and measurements that are being carried out on the MEP/HVAC systems, in the following given order (see Figure below): a) Completeness checks, b) Installation checks, c) Functional checks and d) Functional measurements.

Required step	Purpose	Purpose
A. Completeness checks (step 2 of the guidelines)	To ensure that the HVAC-system has been delivered in accordance with the design	Comparison of components with design, Compliance with technical rules, Cleanliness, Storage on site, Documents necessary for assembling and operating
B. Installation checks (step 6 and 7 of the guidelines)	To ensure that the components are mounted according to the manufacturer's instructions	Self-instruction and self-inspection with the use of INSITER tools, Accessibility, Positioning, Protection, Air- and water tightness
C. Functional checks (partly step 7 and part of commissioning)	Verifying the operation of components and the HVAC system	Component settings, Balancing the system, Operation of components and system, Putting the system into use
D.1 Functional measurements (partly step 7 and part of commissioning)	Verifying on a statistical basis that the system achieves the values according to the design	Determine which measurements and recordings are necessary, Extent of functional measurements, Measurements, Comparing results with the design
D.2 Special measurements (if necessary)	In case of doubts concerning the quality of parts of the system	Determine which measurements and recordings are necessary, Determine uncertainty of the measurements, Measurements
Final check (report)		

The integration of the new approach and the 8-steps in above Figure is illustrated in Figure 94 below.

Figure 116 the new diagnosis approach in the INSITER 8 -steps methodology

8 Example of practical use of INSITER according to the 8-step methodology

STEP 0 - Log-in & work schedule

The construction worker logs-in to the mobile application and receives a schedule and an overview of the activities that he has to do during the day. If he has to do a task that he has never performed before and he wants to get introduction in advance on a format of a video or other supporting document, he can find available material through links. Following the scope of the guidelines, he focuses on critical EeB (energy-efficient building) components. He selects the critical EeB component that he has to work with according to his daily tasks and he starts the "guiding tour" through the INSITER 8-Steps based application.

STEP 1 - Mapping

The construction worker in this step needs to capture the conditions and to compare them with the as-is situation. He begins his work by defining/mapping the location/room/space within the building where he needs to work for the installation/refurbishment of the critical EeB component. He goes to the location and he makes a preliminary evaluation of the actual conditions on site. He can retrieve reference material for main energy-efficient and quality construction errors to be checked.

Note: In case he detects criticalities, in the scenario of refurbishment, and it is needed to take measurements with special equipment, he notifies the construction manager and specialized personnel arrives and performs the required measurements

STEP 2 - Checking of ordered components

The critical EeB components to be installed are delivered on the building site. Using QR or RFID scanning tool, the construction worker checks whether these are the correct components as specified in the BIM model and the technical documents. In this step, he can check the correctness of the delivered components on site before assemble them, or/and retrieve the components ID and visualize the positioning of it.

STEP 3 - BIM for on-site construction

This step includes visualization of the building or the critical EeB components in BIM. Using the mobile device, the construction worker opens the BIM model of the specific part of the building where he has to perform his work with the critical EeB component. In this BIM model, he can observe how the critical EeB components are modelled and integrated within the building and use it as a reference for his actual work on site.

STEP 4 - BIM-based Augmented Reality

Using the mobile device (smartphone, tablet or Hololens) equipped with an AR application, the construction worker projects the BIM model of the new HVAC components to be installed onto the real spatial environment. This step can work complementary with Step 5.

STEP 5 - Clash detection during construction

During this step, the worker on site can project the designed situation (correct situation) of the critical EeB components on real situation within the building, while focusing on the criticalities (clashes). He facilitates AR to check if the critical EeB component to be assembled really fit within the intended building part/space/room, i.e. no "clashes" with building components.

STEP 6 - Self-instruction

The construction worker opens the manual documents/videos/animations where the mounting of the critical EeB components is described in a step-by-step process with easy guidance and hints/warnings of common errors to be avoided. As an INSITER tool for this step has been developed the mobile application, where the mounting process-critical assembly activities can be simulated and supporting reference material can be given.

STEP 7 - Self-inspection

During this step, the worker on-site will check his own work with the help of checklists. Subsequently, if needed, he notifies a specialist to measure the exact performance using specialised equipment. The measurement image (thermal, acoustic etc.) can be either superimposed to BIM or AR for visual evaluation, or kept for integration into the BIM model later on of-site for the definition of the as-is situation and the equivalent calculation of the actual performance of the building according to how components were assembled in reality.

Note: In case it is needed, the measurements with special equipment will be performed by a specialist, after the construction worker notifying him. The evaluation of the result will be done off-site as time is required for the retrieval of the measurement results.

STEP 8 - Final check

After collecting data from all the previous steps, the final step consists of the final evaluation of the work to be delivered. The construction worker completes his assignment by reporting on the finished work, including some photos taken on-site. He should also note errors or doubts, if any, into his digital report through the mobile application. The site supervisor opens this report, and gives approval or asks for rework. The approved works appear on a common INSITER dashboard (off-site) showing the level of quality and performance during the on-site process. Quality, time and cost evaluation can be monitored like that by the construction managers. The INSITER dashboard continually receives info. The dashboard works with the traffic light system:

Red: Not OK/ rework

Orange: Doubt decision by .....

Green: OK

9 Summary

The new "8-step self-inspection" method in construction and renovation includes the following steps:

The INSITER Process

| 1. Mapping | 2. Checking | 3. On-site BIM | 4. BIM-based AR | 5. Clash detection | 6. Self-instruction | 7. Self-inspection | 8. Decision making |

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1. Mapping: Identifying the actual conditions of the construction site
2. Self inspection during purchasing, production and delivery of prefab components.
3. Modelling the (existing) building, terrain, environment in a building information model (BIM).
4. Creating BIM-based AR (Augmented Reality) and deploying it in a project for self-instruction and self-inspection.
5. Virtual validation of quality and performance through BIM control and clash detection.
6. Self-instruction during the preparation and logistics of the construction site and during construction.
7. Self-inspection during construction, renovation and maintenance.
8. Final check.

10 Conclusions

The INSITER toolset combines numerous tools with the 8-step methodology process in a unique way. The advantages are:

- The applied 3D models have a high degree of quality through clash detection, model checking and point cloud processing steps incorporated in the process.
- Workers on-site know exactly which tools to use for a certain step of the process.
- Workers on-site have instruction material of various kinds available.
- Workers on-site have all kinds data available and at hand (documents, video's, interactive step-by-step).
- Workers on-site can apply Augmented Reality technology for comparing the reality against the model and animated training material.
- Workers on-site can check their own work via digital checklists.
- Workers on-site can communicate via the tools (observations, defects and escalation).
- Project managers are supported in their decisions by monitoring the KPI dashboard.