INSITER INTUITIVE SELF-INSPECTION TECHNIQUES

Field Validation and Demonstration Reports and Recommendations

Deliverable number: Merge D5.4and D5.5

Deliverable Reports D5.4 and D5.5, Issue date on 09 November 2018

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

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

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Issue Date	09 November 2018
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Colophon

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

Executive summary

Deliverable D5.4 *Field validation report and recommendations* is a follow-up of D5.3 *Case study elaboration, field validation protocols and equipment calibration* within the framework of WP5 and under the umbrella of T5.2 *Validation in new construction and refurbishment*. T5.2 ends at M36 and D5.4 is the final deliverable within this task dealing with site test preparation and the assigned qualified validation of the INSITER methodology and its expected performance level. D5.4 consists especially of precise technical definitions and elaborated detailing of use cases´ specific testing approaches and the preparation for the life validation activities on site based on the expectations of valuable conclusions. As a core part of this deliverable the INSITER methodology performance is validated at life demonstrator level based on defined features. The original focus of deliverable 5.4 has been changed due to an inconsistency of the DoA as the testing activities are planned starting at M37 and the description of the deliverable was focusing on test results which is impossible in terms of the planned schedule.

The remaining deliverables in WP5 at Y4 of the project focus on life tests and analysis of results at building sites and the technical proof of improvement of the quality assurance while applying the INSITER tool and methodology. In D5.3 the six INSITER demonstration sites have already been introduced and a definition and an assignment of use cases have been realised. The generic description of the current 16 use cases pre-defined in D5.3 provides an outline as a framework for the life tests to be carried out in different thematic fields related to the developed story boards and the demonstrators. In D5.4 the use cases have been validated against the INSITER methodology following the specific testing needs and the equipment to be applied on site in future application.

Based on the use case approach and the validation of the INSITER methodology performance at demonstrator site level D5.4 highlights now specifically the foreseen embedded activities stepwise in coordination with close relation to the INSITER application guidelines according the samples provided already in the drafts of D1.2 *Guidelines for self-inspection in new construction* and D1.3 *Guidelines for self-inspection in refurbishment*. The definitions of the stepwise testing activities summarised in this deliverable are connected with an outlook on expected results in order to create thresholds for upcoming and foreseen validation activities on site and a validation of the INSITER methodology at the same time. These demonstration activities have been started at M36 according to the DoA -see overview of timing of testing activities below.

The results of life tests are documented in D5.5 *Field demonstration report focusing on involving stakeholders in real demonstration cases* -former D5.5 and D5.6 are merged into D5.5 (see revised DoA)- due at M45. Within the final review meeting it was decided to merge and update D5.4 and D5.5. The reason for merging is the harmonisation and the improved consistency of the contents as different demonstrators have been treated at different time slots meanwhile. Therefore, the description of contents for this deliverable is now summing up the contents of both deliverables.

The stakeholders have been integrated in the testing and monitoring activities at practical workshops that took place on site and besides real actions at life test building sites in order to gain qualified feedback on the performance of the INSITER tool and the methodology. All life test results of all demonstrators and related use cases will be cross-case analysed and benchmarked as a final analysis of results and highlighted in D5.7 *Cross-case analysis and benchmarking* as defined in the revised DoA due at M48.

The most important result of this merged deliverable D5.4 + D5.5 is the validation of the INSITER methodology as the final check of the software tools´ contents and the technical and timing preparation of onsite tests that have been performed at 6 demonstrators in Europe starting at M37. These demonstration projects are related to new construction, retrofitting and maintenance, as well and as additionally foreseen and already described in D5.3 the important finishing prefab-process at the DRAGADOS factory. Nevertheless the check of the final performance of the buildings and the positive impact of self-inspection addressing the following aspects: Building physics analysis; reliability of structure; preferred materials and their assembly demands; and indoor climate have not been embedded in D5.4.
The reason for merging and updating the deliverable is the delay in terms of availability of sites at the right time. The above mentioned aspects are documented in this merged deliverable, now.
The quality of final prefabrication as a result caused by the interaction between modelling and finishing prefab activities at factory level and the correlated site delivery and logistics have been identified as the most relevant quality assurance problems causing extra ineffective efforts and poor quality performance. The overview of the current projects shows the variety of testing activities -size, type, use, country- foreseen and the proof of the application feasibility of the INSITER tool and methodology from the perspective of the practical application at the prefab factory and the use on building sites of different kinds in various European countries:

Demonstrator 1: Health Centre Cologne, DE, responsible INSITER partner 3L. The Cologne demonstrator is a roof top extension with prefab light-weight elements on an existing building erected in 2012. This project is defined as a hybrid, because an additional new part of a building will be connected structurally with an existing building without retrofitting it. Field demonstration activities focus on three use cases -see chapter 2:

1. Scan of QR code,
2. Geometric check of the ground sill and
3. Application of AR.

The tests based on the use cases have been performed on site and at the factory in the first half of 2018. The involved partners representing different SIG´s and stakeholders are:

1. 3L architects, design partner + associated general planning team, building permission consultant, tendering and site steering, responsible INSITER partners: Klaus Th. Luig, Dieter Jansen
2. Prima Colonia Besitz GmbH, client, owner and investor, contact: Veronika Lenze
3. Tegralis Köln Verwaltungs GmbH, general tenant, contact: Veronika Lenze
4. HVC, BIM model, 3D laser scan and clash detection, Jan Derrick Braun

5. FHGIPA, Augmented reality application, Günther Riexinger
6. Brünninghoff, general contractor, turnkey offer, contact: General manager Mr. Steffens

Stakeholders involved: Client, Designers, architects, engineers, prefab company, site workers and tenants

Demonstrator 2: Cartif-3, E, responsible partner Cartif. Cartif-3 is an existing prefab nearly zero energy research building. It contains large facilities for real scale chemical/industrial prototypes testing and offices. Field demonstration activities focus on checking of measured values of building components, measurement of thermal performance and commissioning of solar thermal systems related to maintenance demands. Field demonstration activities focus on three use cases –see chapter 6:

1. Checking and approval of geometrical measures.
2. Assessment of the building envelope quality.
3. Commissioning and surveying of the solar thermal system.

The tests based on the use cases were on-going up to M45 (September 2018). CARTIF is the owner and manager of CARTIF-3 building. The involved partners representing different SIG´s and stakeholders are indicated in the particular use cases (column "responsible partner", see chapter 6, accordingly).

- Partners involved: CARTIF, HVC, 3L, DEMO, UNIVPM, and SIEMENS.
- Stakeholders involved: building owner/manager, construction or architectural company, surveying company, energy engineering or consultant, construction engineering or consultant, solar panel installer.

Demonstrator 3: Concetto Marchesi, I, responsible partner AICE. The "Concetto Marchesi", located in the eastern part of Pisa, is an educational facility built in the 1970s with a modular construction grid, a precast structure and prefab envelope components. The building is in poor maintenance condition and therefore deep inspection procedures will be performed. Field demonstration activities focus on geometrical consistency, testing of thermal bridges and checking of the connections between existing building and additions. Field demonstration activities focus on 3 use cases –see chapter 5:

1. Checking of geometric consistency
2. Checking of thermal performance on 2D components
3. Checking of the connection between existing building and additions using Augmented Reality

Use case 1 has been completed in November 2018. The tests based on use cases 2 and 3 were planned in the second half of 2018. The involved partners representing different SIG´s and stakeholders are:

1. AICE Consulting, building inspectors, design partner, building permission consultant. Responsible INSITER partners: Antonfranco Pasquale, Benedetta Marradi
2. Provincia di Pisa, client, owner and investor, contact: Genoveffa Carluccio
3. HVC, BIM model, 3D laser scan and clash detection, Jan Derrick Braun
4. UNIVPM, On-site thermal measurements: Milena Martarelli, Giuseppe Pandarese
5. FHGIPA, Augmented reality application, Günther Riexinger

Stakeholders involved: Client, designers, architects, engineers and inspectors.

Demonstrator 4: Hogekamp, NL, responsible partner DEMO

This demonstrator is a deep renovation and transformation project of an abandoned building of the University of Twente in Enschede (NL) into a student housing (75%) and a hotel (25%).

The field demonstration activities focus on the testing and inspection of new facade panels and parts of the new MEP system. Field demonstration activities focus on four use cases –see chapter 4:

1. On-site comparison of the façade panels and windows with the BIM model
2. Thermal bridge identification before project delivery
3. Clash detection
4. Application of Augmented Reality (AR)

The involved partners representing different SIG´s and stakeholders are:

1. DEMO Consultants B.V. (DMO) – main contact with the building owner and developer, visual on-site comparison of the façade panels and windows with the BIM model
2. Camelot Vastgoedbeheer B.V. – the building owner and investor, property manager
3. Universita Politecnica delle Marche (UNIVPM), Giuseppe Pandarese – thermal scanning
4. HOCHTIEF Vicon GMBH (HVC), Jan Derrick Braun - clash detection, Fraunhofer-Institute IPA (FHGIPA), Günther Riexinger - Augmented Reality application

Demonstrator 5: Sustainer Homes, NL, responsible partner DEMO. The construction of two new test beds by Sustainer Homes at The Green Village: the Office Lab and the Living Lab, function as a demonstrator for INSITER and its structure has already been completed. The two new prefab buildings are based on wooden modules, built in a factory using renewable materials. The modular system offers an expandable character. The field demonstration activities focus on three use cases - see chapter 3:

1. Comparison of the IKEA-like self-instruction manual with the actual situation on site;
2. Identify right moments for visual inspection and inspection with equipment;
3. Compare the as-designed situation with the as-produced and as-built situation.

Some on-site activities have already been performed: including the following of the mounting on-site for observations and a theoretical validation of the applicability of the INSITER methodology. Some more tests based on the use cases have been performed in the second half of 2018. The involved partners representing different SIG´s and stakeholders are:

1. DEMO Consultants B.V. (DMO) - on-site observation activities, contact with Sustainer Homes and Green Village Foundation
2. Sustainer Homes, design contractor: designers, architects, engineers; contact: Nick de Haas-Project Manager;
3. Green Village Foundation & Delft University of Technology, owners and investors, contact: Tim Jonathan (MSc) - Programme Manager Buildings
4. Province of South-Holland, municipality of Delft, Alliander, Gasterra and others, investors via the European Regional Development Fund platform
5. RDF, BIM model, mobile application

Demonstrator 6: DRAGADOS Factory, E, responsible partner DRAGADOS.

The demonstration project chosen is a 150 m² modular building, designed to serve as a space for social activities for the neighbours of the area. This project allows testing the final prefab procedures. The building is made of three independent one storey units following the still on-going detailing process made of 5-6 modules each. Each unit is "connected" to the other two by open air spaces. The building includes a multi-purpose main area, restrooms, warehouse, offices, etc. The final location of the building will be Seville.

The modules are almost entirely produced in the factory of Las Cabezas de San Juan near Seville (Spain) and then shipped on-site for final assembly. The modules are produced using low environmental impact materials, using as much as possible recycled and low cost materials. All necessary services including electricity, data, HVAC and MEP have been integrated at factory level, and final connections will be carried out on-site. The demonstration activities will focus on three use cases - see chapter 7:

1. Window placement on prefabricated panel
2. Thermal and air tightness evaluation of the module's facade to ensure compliance with project requirements
3. Acoustic and air tightness evaluation of the module's facade to ensure compliance with project requirements

Stakeholders involved: Client, Designers, architects, engineers, prefab company, site workers and tenants

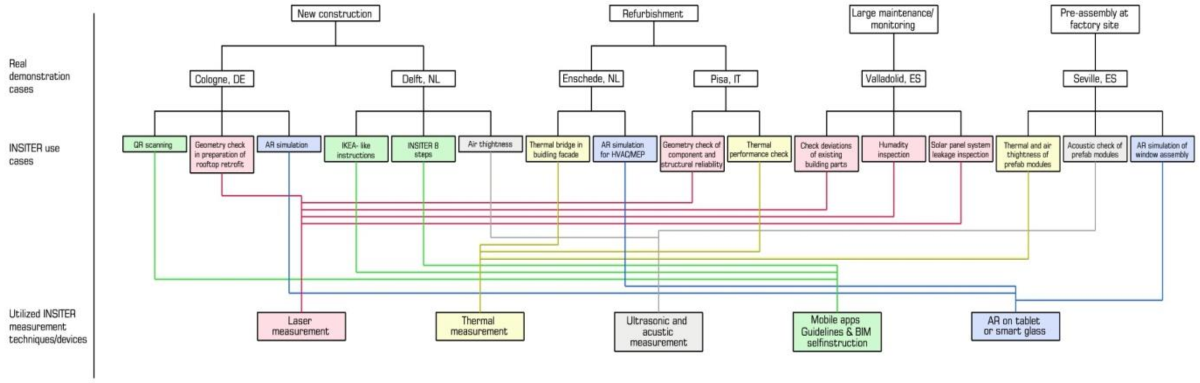


Fig. 1: scheme of demonstrators and use cases applied

The testing overview provides an insight in the foreseen activities of site and factory testing. Nevertheless, regular deviations caused by typical site steering activities took place.

Within each of the 6 demonstrators two or three critical construction topics have been identified and developed as use cases. The INSITER methodology has been validated regarding the issues that are defined in this deliverable. To prepare the INSITER toolset for the aimed use cases it is essential to describe the proposed testing processes on site in detail. The storyboards are describing actions related to the INSITER toolset in the given construction situations. This enables the INSITER project to adjust the required software functionalities and to prepare the BIM models as well as the IT environment in the most suitable way for real testing purposes on site. The use cases are defined and used as practical samples in order to validate the INSITER tools and methodologies. Related to the quality assuring self-inspection and self-instruction methodology supported by the INSITER tool the testing needs and processes on site are prepared and pre-defined.

Typology	Dmonstrator	Use case	Device
New construction	Cologne	1 Scan of QR code	QR scanner
		2 Geometry check	Laser scanner
		3 AR application	AR
	Delft	(1 Comparison of the IKEA-like self-instruction manual with the actual situation on site)	X
		2 Identify right moments for visual inspection and inspection with tools	Acoustic measurement
		3 Compare as-designed with as-delivered and as-built situation (overall)	Acoustic measurement
Refurbishment	Enschede	1 Building envelope – Inspection of deviations or flaws at the placement of new facade	Thermal measurement
		2 MEP system – AR on-site simulation	AR
	Pisa	1 Checking of geometric consistency and BIM validation	Laser scanner
		2 Checking of thermal performance on 2D components	Thermal measurement
		(3 Checking of the connection between existing building and additions using AR)	X
Maintenance	Valladolid	1 Check and approval of measured values	Laser scanner, deviation analysis
		2 Building envelope quality	Laser scanner
		3 Commissioning of the solar thermal system	Thermal measurement
Factory	Seville	1 Thermal and air tightness evaluation of the module's envelope	Thermal measurement
		2 Acoustic evaluation of the module's facade	Acoustic measurement
		3 Application and demonstration of INSITER BIM based AR Apps	AR

Tabel 2: list of demonstrators and use cases applied

Furthermore integrated in the second part of each chapter for the single demonstrators the use cases show their characteristic positive impact of self-inspection on building physics performance, as U-value and insulation, material use and application, assembly demand and indoor climate.
The applied devices and testing areas are assigned to the demonstration cases and the typology of application. All Typologies mentioned in the DoA are covered. The use case overview per demonstrator proofs the holistic application of devices and assigned process.
The INSITER methodology and toolset has been developed based on high end scientific and industrial knowledge. Measuring and testing processes have been analysed, applied and approved at the laboratory, the factory and the field. The objective was the optimization of the use and the integration for real life testing. As the practical results and the application and documentation have been the focus of WP5, tests at various demonstration sites have been performed. Especially at European level there is a need to involve all stakeholders and receive the feedback from different countries representing the demands of e.g. various geo–clusters, building law and other building cultures influencing the quality assurance of the building process especially if the energy-efficient building sector is the target.

There is a dilemma in demonstration activities that should cover all the above mentioned aspects and give evidence that the collected results are transferable from a single demo site in one country following just its characteristics to other countries. The practical motivated INSITER decision was to go for the use case approach in order to localise the results and analyse the transferability. Furthermore it was obvious that the embedding of single use cases in the on-going building process on sites is complicated enough -timing, organisation, integration, publication, especially if a research and development project is “harming” the regular approach, at least it is steeling time from the project and the stakeholders involved. Therefore focusing on a full-spectrum of field validation requests a use case oriented organization.

List of acronyms and abbreviations

- **AEC:** Architecture, Engineering and Construction industry
- **AR:** Augmented Reality
- **BIM:** Building Information Modelling
- **BLC:** Building Life Cycle
- **CAD:** Computer Aided Design
- **CNC** Computerised Numerical Control
- **DoA:** Description of the Action
- **EE:** Energy Efficiency
- **EeB:** Energy Efficient Buildings
- **GUI:** Graphical User Interface
- **GUID:** Globally Unique Identifier
- **HFM:** Heat Flow Method
- **HTML:** Hypertext Markup Language
- **HVAC:** Heating, Ventilation, Air Conditioning
- **ICT:** Information and Communications Technology
- **IFC:** Industrial Foundation Classes
- **ISO:** International Organisation for Standardization
- **KPI:** Key Performance Indicator
- **LCA:** Life Cycle Assessment
- **LCC:** Life Cycle Cost
- **M&E:** Mechanical and Electrical services
- **MEP:** Mechanical, Electrical, Plumbing
- **MTT:** Methods, Tools and Techniques
- **NDT:** Non-destructive test
- **nZEB:** Nearly Zero Energy Building
- **QC:** Quality Control
- **QR code:** Quick Response Code
- **SIG:** Special Interest Group
- **TCO:** Total Cost of Ownership
- **URL:** Uniform Resource Locator
- **VR:** Virtual Reality
- **WBS:** Work Breakdown Structure
- **ZEB:** Zero-Energy Building

Definitions

Project

INSITER demonstration deals with six real projects. The demonstration, validation, testing and training activities take place on these real building sites.

Physical settings

There are three different natures of testing levels and related cases:

1. Lab testing case: performed at the laboratory or artificially created test sites at the factory
2. Factory testing case: performed at the factory related to real projects and its components
3. Field (on-site) demonstration case: performed at building sites

Hybrid

A project is defined as a hybrid, if an additional new part of a building will be connected structurally with an existing building without retrofitting it.

Self-inspection

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

Self-instruction

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

Storyboard

A storyboard is a description of a follow up of steps in the real workflow related to a single building site. The storyboard approach identifies important project steps and interaction. The objective is to create use cases that are important related to characteristics for the application of the INSITER tool at building sites at the most effective and efficient level. Storyboards are representing a characteristic and important selection of building sites´ workflow.
For example: describing as a whole in a 'storytelling way' how the geometric checking is done –how, where, who, etc.

Use case

A use case is defined as a sample case relevant and valuable for INSITER testing needs based on a storyboard representing the full workflow. The characteristics of the use case are transferable and therefore the results help to validate the INSITER methodology and tool application. For example: checking the geometric accuracy –what is the goal, what is the criticality, etc. A use case can take place within a lab, factory, or field case.

Action

Is describing a specific activity within the storyboard – e.g. calibrating measurement device, taking measurement.

Actions are related to the 8-Step INSITER methodology of quality assurances: mapping, checking ordered components, etc. These steps must be consistent with the overview of the 8-Step INSITER method (see DoA p.15, part B for detailed description):

1. Taking an accurate reference situation: Mapping the actual technical conditions of the site and building, and performing economic valuation of the property and land.
2. Selecting high-performance building components: Self-inspection at procurement, production and delivery of prefab components.
3. Creating realistic models of buildings and sites and their performance target: Modelling of the building, site and surroundings in Building Information Model (BIM).
4. Virtual validation of quality and performance in BIM: Model Checking and Clash Detection; as well as value and process optimisation by Virtual Reality simulations.
5. Intuitive use of Augmented Reality (AR) by workers on site: Generating and deploying BIM-based Augmented Reality (AR) for self-instruction and self-inspection.
6. Validating site conditions: Self-inspection during preparation of sites and logistics.
7. Validating preliminary results: Validating Self-inspection and self-instruction during construction / refurbishment / maintenance process.
8. Connecting performance target and user operation / behaviour: Self-inspection during pre-commissioning, commissioning and project delivery; self-instruction for users.

Assembly Phase

The process of prefabrication of the building parts at factory level including an analogue mock-up at the factory.

Construction Phase

The process of constructing the building to meet the criteria established during the design phases and where the building performance as outlined in the construction documents is validated through observations and testing (source: NIBS Guideline 3-2012 Building Enclosure Commissioning Process BECx This Guideline is for Use with ASHRAE Guideline 0-2005: The Commissioning Process, 2012). Within the construction phase all processes related to the placement of prefab components at the site are embedded.

Maintenance Phase:

The objective is to repair unscheduled and scheduled deficiencies during the time period in which they occur. This includes preventive maintenance for buildings, structures, and installed building equipment (IBE) as recommended by the manufacturer. It also includes engineering and/or contracted Architectural and Engineering (A&E) services that support planning, design and execution of maintenance activities.

Remarks from EC Expert at M47 Review Meeting

<table>
<tr><th>Remarks from EC Expert at M47 Review Meeting</th><th>Addressed in revised deliverable</th></tr>
<tr><td>D5.4
Request for revision comment:
• The report would have shown the final performance of the buildings and the positive impact of self-inspection addressing the following aspects: building physics analysis (U-value, sound insulation); reliability of structure; preferred materials and their assembly demands; and indoor climate. This was not adequately addressed in report. To be added.</td><td>• The real energy consumption (in kWh) can only be measured in the occupation phase that follows the construction phase. During the construction phase, we can measure the deviations in energy-related properties of the building parts. For example in Delft case, we performed measurement and calculation during addressed the construction process which showed the R/C-value or U-value of the building envelopes. The estimate of energy consumption can be calculated using the method described in D1.5, but the actual energy consumption in building operation is not measured as it is out-of-scope of INSITER. Building physics analysis, reliability of structure, preferred materials and their assembly demands and indoor air climate have been added to the demonstrators. Building physics analysis, reliability of structure, preferred materials and their assembly demands and indoor air climate have been added to the demonstrators.</td></tr>
<tr><td>D5.5
Request for revision comment:
• The approach, methodology and global INSITER self-inspection methodology and tools will be validated by external Different numbering of demo cases compared to D 5.4, a clear and homogenous structure and information through different documents should be presented
• ...will serve as guidelines to organize the demonstration activities as a template to document the outcomes. Also includes the format for input to training development
• information presented not structured in detail
• format for training development not presented
• T 5.3 states: the demonstration activities will show evidence of the final performance of the buildings and the scale of improvements made by using the prototype INSITER Systems and Methodology.
• not addressed sufficiently in D 5.5
• The approach, methodology and global INSITER self-inspection methodology and tools will be validated by external stakeholders under real working conditions
• not addressed sufficiently in D 5.5
• contractors on-site technical staff, subcontractors and clients will be engaged before, during and after the demonstration, not only witness INSITER technologies functionality but use them and evaluate their performance
• not addressed sufficiently in D 5.5</td><td>• D5.4 and D5.5 are merged and restructured and are presenting a continuity with D5.3 providing a clear and homogeneous structure.
• The contents for training have been transferred to partners ISSO and are the basis of the online training developed in WP6.

• The EC PO and Reviewer expect that the whole INSITER methods and measurement techniques are deployed completely within 1 case. This is not possible due to the nature of the different projects (some under construction, some under refurbishment, and some in monitoring to plan large maintenance or renovation). The combination of all cases cover the full scale of INSITER, in summary:
o Cologne – laser scanning
o Delft – air tightness
o Enschede – thermal, AR
o CARTIF 3 – monitoring

• Workshops with different stakeholders have been performed on the demonstration site in Enschede in May 2018 and at the DRAGADOS factory in September 2018. The results are documented in D5.7. Especially contractors on site gave their valuable feedback on the application.</td></tr>
</table>

Table of contents

1. Introduction

The scope of D5.4 and D5.5 is covered following the use case oriented and structured approach:

Characteristic and important fields of action related to an enhanced quality assurance based on KPIs have been identified in correlation with the input received from WPs 1, 2, 3 and 4. Furthermore the data quality needed and the software for operation of measurements of any kind and for the integration and evaluation of data are defined and checked in terms of feasibility and applicability in order to validate the holistic offer embedded in the RE Suite developed by INSITER partner DEMO.

The merged deliverables focus then on life tests and analysis of results at building sites and the proof of improvement of the quality assurance while applying the INSITER tool and methodology. In D5.3 the six INSITER demonstration sites have been introduced and a definition and an assignment of use cases has been realised. The generic description of the current 16 use cases defined in D5.3 provides an outline as a framework for the life tests to be carried out in different thematic fields related to the developed use cases and demonstrators. In D5.4 the defined use cases have been validated against the methodology following the specific testing needs and the equipment to be applied on site.

Based on the use case approach and the validation of the INSITER methodology performance at demonstrator site level D5.4 highlights specifically the foreseen embedded activities stepwise. The definitions of the stepwise testing activities summarised in this deliverable are connected with an outlook on expected results in order to create thresholds for upcoming and foreseen validation activities on site and a validation of the INSITER methodology at the same time. These activities were planned starting at M36 according to the DoA –see overview of timing of testing activities at the executive summary.

The results of life tests are documented in D5.5 Field demonstration report focusing on involving stakeholders in real demonstration cases -former D5.5 and D5.6 are merged into D5.5 (draft of revised DoA)- due at M45.

The stakeholders have been integrated in the testing and monitoring activities – see overview at the executive summary, too- at practical workshops in order to gain qualified feedback on the performance of the INSITER tool and the methodology.

All life test results of all demonstrators and related use cases will be cross-case analysed and benchmarked as a final analysis of results and highlighted in D5.6 (as defined in the draft of the revised DoA) Cross-case analysis and benchmarking due at M48.

The most important result of this deliverable is the validation of the INSITER methodology as the final check of the software tools´ contents and the technical and timing preparation of onsite tests that have been performed at 6 demonstrators in Europe starting at M37. These demonstration projects are related to new construction, retrofitting and maintenance, as well as additionally on the finishing prefab-process at the DRAGADOS factory.

The quality of final prefabrication as a result caused by the interaction between modelling and finishing prefab activities at factory level and the correlated site delivery has been identified as the most relevant quality assurance problem. The overview of the current projects shows the variety of testing activities foreseen and the proof of the application feasibility of the INSITER tool and methodology from the perspective of the practical application at the prefab factory and the use on existing building sites of different kinds.

2. Real demonstration case of new construction in Cologne, DE

2.1 Changes compared to the original plan described in D5.3

No changes. All use cases have been performed on site and at the factory even if the realization is postponed.

2.2 Field Validation / demonstration for each use case

The site is located in Cologne, West Germany. The rooftop extension is planned upon the 2rd floor of the existing building as the 3rd floor. The loads of the additional storey with a total floor space of approx. 800 m² were already pre-calculated when the building stock was erected in 2012 and the staircase and the elevator have already been built by that time, as well.

Figure 2: Existing building

There are particular demands for the construction process, because the existing flat roof insulation will have to be removed before the new construction can be placed. The construction process is depending on the weather and the new storey will be erected while all the business activities of the tenants in the existing building will not be stopped. So there is a strong need for a very swift construction process in order to minimise the sound disturbance and the risk of water ingress. The rooftop construction will be consisting of lightweight prefab external walls for high performance thermal and sound insulation. The walls and the new roof will be mounted on a primary steel construction. The time frame of the realisation is caused by weather conditions as the existing sealing has to be removed and a new sealing has to be established as soon as possible.

The late spring of 2018 was identified as the appropriate time for this critical action facing the risk of causing damage on the existing stock. The envelope of the rooftop extension will be finished in 4 weeks and it is planned that the turnkey project will be submitted after 3 to 4 months.

2.2.1 Use Case 1: Scan of QR code

Additionally to the generic description in deliverable D5.3 of the Demo Case 1 for the Health Care Centre, Cologne, this chapter refers to a more functional description of the now precisely defined use case of QR code scanning related to life testing activities and the validation of the INSITER methodology. This description of the detailed process steps from scanning a QR-code on site –after having assigned a QR-code already in the BIM model- to the retrieval of information coming from a BIM model serves as a base for developing the required functionalities.

The use case QR code scanning is a functionality embedded in the second step of INSITER´s eight step methodology, which is referring to “Checking of Components”. It is intended to validate the correctness of the delivered prefabricated component on one hand and on the other hand it will provide information to the site team about where to install and position the delivered component. Furthermore the technical data are assigned and the components can be identified.

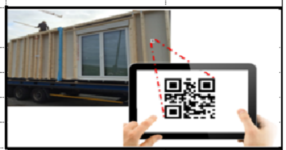
INSITER D5.4; data sheet use case					
Use Case 1.1		**Scan of QR code**			
Relevant Demonstrator		Health Centre Cologne			
Responsible Insiter Parter		3L			
	description	responsible partner	additional input	time schedule	tools to be used
Step 1	create BIM Model	3L/HVC	Panel producer	done	IFC viewer
Step 2	upload BIM to server	HVC	n.a	done	n.a.
Step 3	production of panels	3L, panel producer	n.a	contracted	
Step 4	inform site of date panels will be ready	3L, panel producer		pending	
Step 5	upload all relevant information to server	3L, panel producer			INSITER guidelines
Step 6	transportation of panels to site	panel producer	transport company		
Step 7	scan QR code	assembler			QR code scanner
Step 8	check and report quality of panels	assembler			INSITER software tool

Table 2: data sheet use case 1.1

In brief there are three important follow up process steps related to the origin QR code scanning procedure:

- Step 1: Scan the QR code on the delivered component
- Step 2: Identify the specific component within the available BIM model
- Step 3: Retrieve information

The QR code scanning is a functionality provided by the RE Suite, which is part of the INSITER´s toolset. Before performing a scan the user has to open the software on a tablet and login to the system with his personal login data.

The following images will provide a deeper insight into these three process steps:

Step 1

Select the menu item **Product identification** and in the camera panel at the right side aim for the QR code on the delivered construction part.
The QR code will be scanned and translated into a specific element GUID for further data assessment.

Figure 3: screenshot

Step 2

When recognized the App will show the model and highlight the part that correspond to the GUID derived from the QR code.
This will provide information about the correct planned location to the site team, where this specific component has to be installed.

Figure 4: screenshot

Step 3

Click on the highlighted construction part and all information related to that part (documents, checklists, images, videos) become available. All related data, which is available on INSITER´s SharePoint site regarding this element, will be provided to the site team for further processing. The QR code scanning is an easy-to-use functionality on one hand and provides all required information to the site team, which makes the tool at the same time very powerful.

Figure 5: screenshot

The QR code scan is a well introduced methodology. The location of the component and its characteristic features supports the quality assurance process in all phases of the components' life cycle: from modelling to prefab quality check and from site positioning to maintenance issues.

2.2.2 Use Case 2: Geometry check of the ground sill

The geometry check of the existing ground sill produced on site against the modelled ground sill is easily done.

The first step is the 3D data collection of the existing concrete structure poured in place or just placed if it is consisting of prefab components. This is done with a regular 3D laser measurement system. The captured data will be analysed by the RE Suite to check the collected data against the idealistic out of failure BIM model. The clash detection action is producing a report focusing on "as modelled" deviations. The data survey embedded in the RE Suite is checking not just deviations but additionally and even more important the significance of the deviations related to:

1. Size, Dimension
2. Geometrical accuracy to angular alignment
3. Geometrical accuracy to flatness.

INSITER D5.4; data sheet use case				INSITER INTUITIVE SELF-INSPECTION TECHNIQUES	
Use Case 1.2		**geometry check of the ground sill**			
Relevant Demonstrator		Health Centre Cologne			
Responsible Insiter Partner		3L			
	description	responsible partner	additional input	time schedule	tools to be used in site testing
Step 1	Preparation and Retrieval of latest IFC BIM Model	HVC	3L, Panel producer	BIM model available	IFC viewer, INSITER RE suite
Step 2	On- site examination	HVC, 3L		At the beginning of construction work (March 2018)	3D laser scan
Step 3	Clash detection	HVC, DEMO	3L	March/April 2018	IFC viewer, INSITER RE suite

Table 3: data sheet use case 1.2

The thresholds in the different categories depend on the prefab system and the characteristic provision of means to cover tolerances in the above mentioned categories. The thresholds will differ from prefab system to prefab system. Deviations at ground sill level are producing on-going and often increasing deviations especially if the building has more floors. In that case the existing and acceptable tolerances are not just dependent on the ground sill but the accuracy is influenced by the number of floors, too. The thresholds can be adjusted at the RE Suite to fit these different demands of clash detection. The figure below is a sample for a threshold overview related to a German DIN norm. A similar table with adjustable threshold is embedded in the RE Suite.

limiting deviations for angular misalignment DIN 18202								
	nominal sizes ≤ 0,5 m	nominal sizes >0,5 m and ≤ 1 m	nominal sizes >1 m and ≤ 3 m	nominal sizes >3 m and ≤ 6 m	nominal sizes >6 m and ≤ 15 m	nominal sizes >15 m and ≤ 30 m	nominal sizes >30 m and <60 m	
floor surfaces, ceiling surfaces, wall surfaces surfaces in stage, surfaces of building elements	3 mm	6 mm	8 mm	12 mm	16 mm	20 mm	30 mm	

Table 4: limiting deviations for angular misalignment according to DIN 18202

Figure 6: 3D laser scan equipment

The collection of data - see step 2 in the use case chart in *table 3* - is done with regular 3D laser scan equipment that shares the data with the BIM model for performing clash detection and creating the clash detection report.

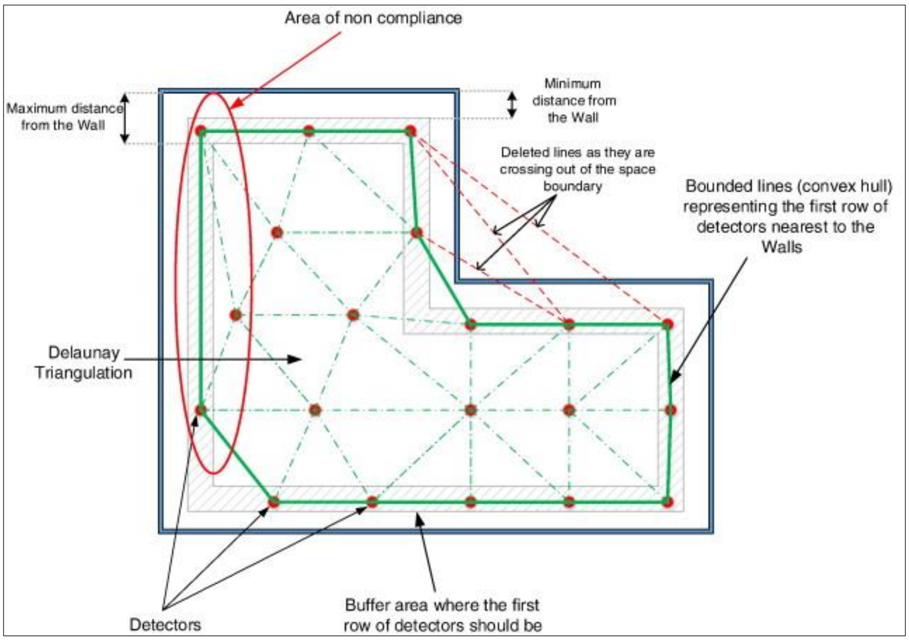


Figure 7: Sample of a deviation overview created as one chart of the clash detection report and shown in the RE Suite

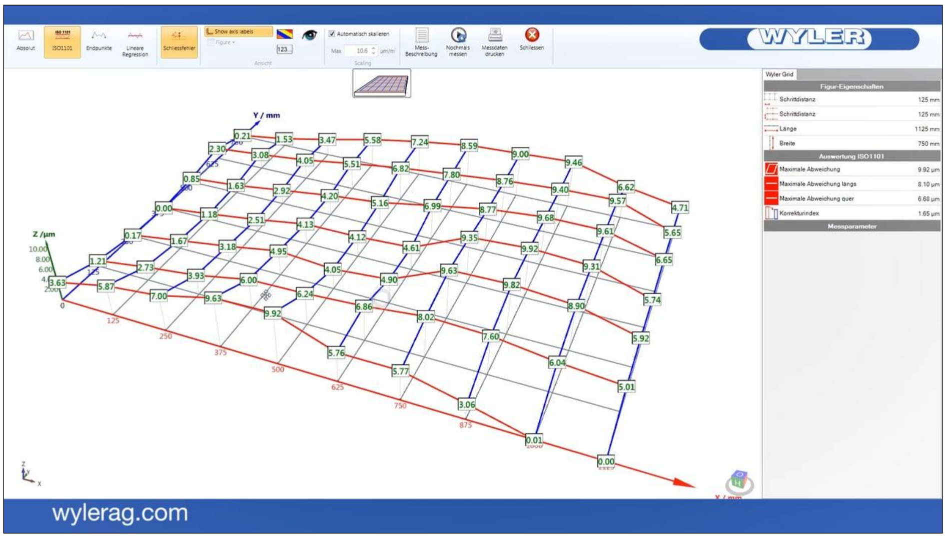


Figure 8: Sample of the 3D overview of the ground sill with deviations provided by a grid and shown in the RE Suite

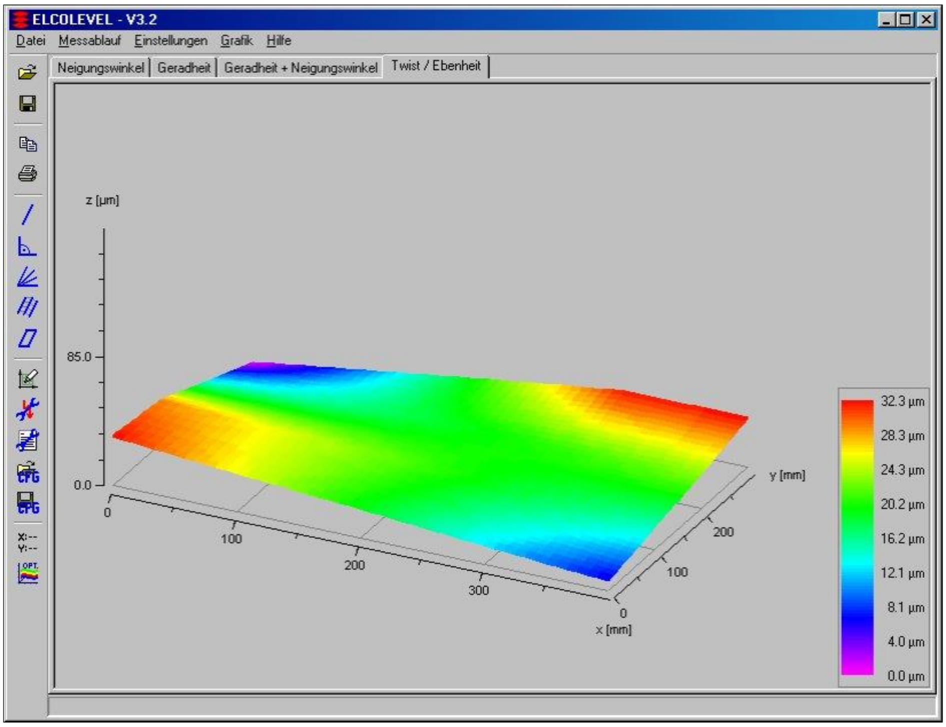


Figure 9: Sample of a deviation analysis related to areas

The threshold of the deviation analysis will differ following the characteristic needs of the applied building system and the solution offer created by the contractor. Therefore the RE Suite is designed as an open and adjustable framework under flexible thresholds that will be inserted by the applying users following the systemic needs of the applied system.

2.2.3 Use Case 3: Application of Augmented Reality

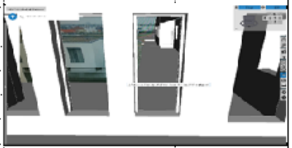
INSITER D5.4; draft template data sheet use case				INSITER INTUITIVE SELF-INSPECTION TECHNIQUES	
Use Case 1.3		**Application of AR**			
Relevant Demonstrator		Health Centre Cologne			
Responsible Insiter Partner		3L			
	Description	responsible partner	additional input	time schedule	tools to be used in site testing
Step 1	Preparation and Retrieval of latest IFC BIM Model	HVC and FhG	3L, Panel producer	1st version done, update in March 2018	IFC viewer, INSITER AR
Step 2	On- site examination	3L	FhG, partners on site	At the beginning of construction work (March 2018)	n.a.
Step 3	Set up of AR tracking system	3L, FhG	partners on site	March/April 2018	INSITER AR
Step 4	Application of AR to verify the assembly location of BIM elements	3L, FhG	partners on site	March/April 2018	INSITER AR
Step 5	Application of AR to evaluate built-in elements and installed components	3L, FhG	partners on site	March/April 2018	INSITER AR
Step 6	Application of AR to access referenced planning information on INSITER SharePoint	3L, FhG	partners on site	March/April 2018	INSITER AR

Table 5: data sheet use case 1.3

In addition to the description in D5.3, the application of the INSITER AR solution on-site has been further refined. During the construction of the new rooftop extension the AR application will be applied within the use case by the architect and construction engineers with focus on the construction consistency of dedicated building elements and prefabricated panels.

Main Steps concerning the application of AR for Cologne Health Center rooftop extension:

- Verification of the assembly location and placement of BIM elements;
- Evaluation of BIM-based built-in elements and installed components concerning construction errors and inconsistencies;
- Access of referenced planning information on INSITER SharePoint.

It is scheduled to perform the evaluations during the use cases, see data sheet above.

During the application of the developed INSITER AR solution for extensive and complex 3D models including BIM and referenced planning data (e.g. instruction manuals), the actors on-site will access and visualize related BIM objects superimposed to the real construction environment. Therefore, the AR computer vision based tracking system is set-up, by applying reference markers within the BIM model and the real environment.

Implemented computer vision based tracking algorithms for multi-marker and enhanced model tracking, along with extensive and complex BIM AR visualization functionalities and data reference system will provide a comprehensive and interactive AR BIM data visualization solution for INSITER and the Cologne AR use case.

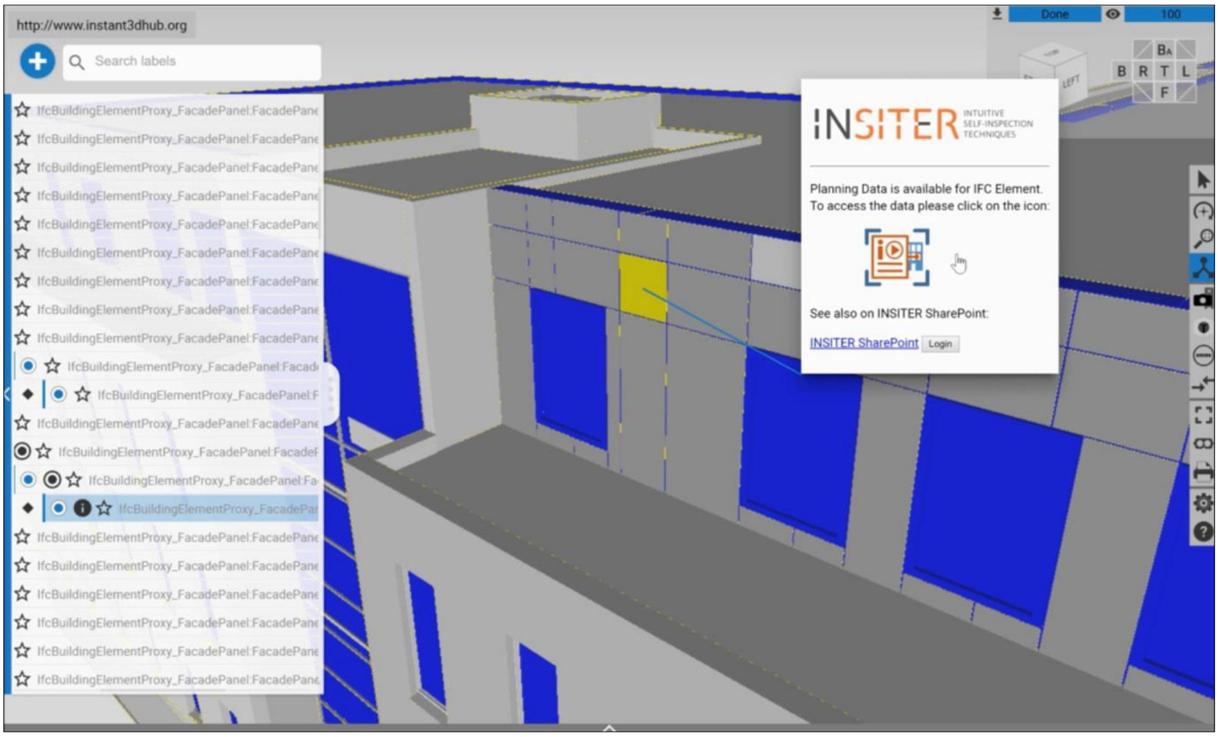


Figure 10: Exemplary BIM element selection of facade element cornering the INSITER Use Case Demo in Cologne with access to referenced planning data

The evaluation steps with the help of the INSITER AR solution during the Cologne demonstration activities are planned to be performed during actual construction work scheduled for March and April 2018.

One scheduled main task will be the verification of assembly locations and placement of BIM elements, by selecting a dedicated panel or facade elements cornering on-going construction work of the Cologne demonstrator.

Within a second step, the already built-in elements and installed components and BIM elements will be evaluated and their correct position and assembly will be verified in detail with the help of AR as illustrated in *Figure 9.* Thus, construction errors and other inconsistencies can be identified by combining the on-site real work environment and as-is state with actual digital planning information and the BIM target state.

Besides BIM IFC 3D-models and model parameters, further planning data provided by partners via the INSITER SharePoint will be accessed as a final step within the Cologne AR use case. This data will include planning documents for dedicated building and façade elements for multiple stakeholders and construction engineers on-site.

As already described in D5.3, the overall performance of the developed AR application will be evaluated along with further on-site tests of the implemented computer vision based tracking technology.

As already presented in Ancona at M24 at lab level the AR application is feasible and attractive to construction workers. The qualified closing of the gaps between the prefab components is one of the most critical steps for creating a dense building envelope. The foreseen AR application helps to assure this important part of quality assurance on site.

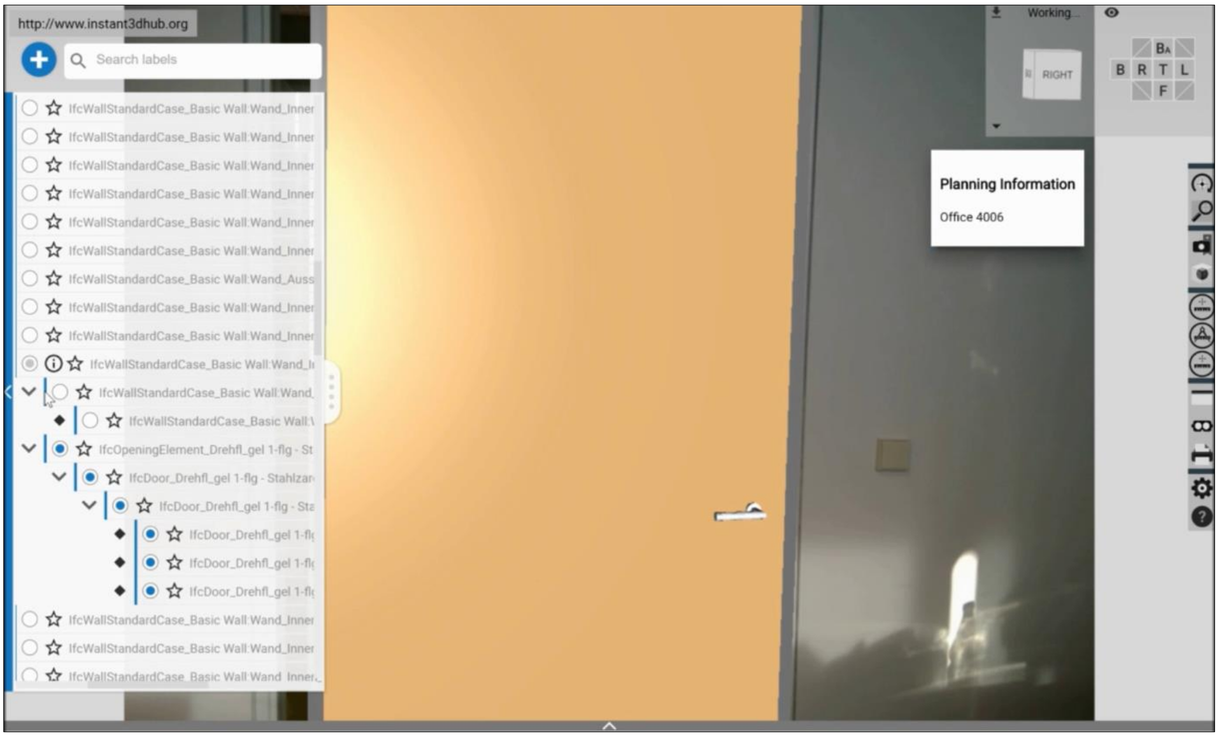


Figure 11: Exemplary BIM element evaluation concerning built-in elements and installed components (door example) for the INSITER Use Case Demo in Cologne

TESTINGS OVERVIEW HEALTH CENTRE COLOGNE

Use case	M36 Nov 17	M37 Dec 17	M38 Jan 18	M39 Feb 18	M40 Mar 18	M41 Apr 18	M42 May 18	M43 Jun 18	M44 Jul 18
Use case 1.1: scan of QR code						Scan of components delivered	Scan of components delivered		
Use case 1.2: geo-metry check ground sill					Laser scan and overlay with as modelled	Continuous monitoring of geome-tric accuracy			
Use case 1.3: AR applica-tion							Connection of compo-nents to existing elevator shaft	Connection of compo-nents to existing elevator shaft	

Table 6: Scheduling of use cases

2.3 Real measurement values / demonstration results from each use case

2.3.1 Description of the demonstration building, purpose of the demo and target group

The site is located in Cologne, West Germany. The rooftop extension is planned upon the 2rd floor of the existing building as the 3rd floor. The loads of the additional storey with a total floor space of approx. 800 m² were already pre-calculated when the building stock was erected in 2012 and the staircase and the elevator have already been built by that time, as well.

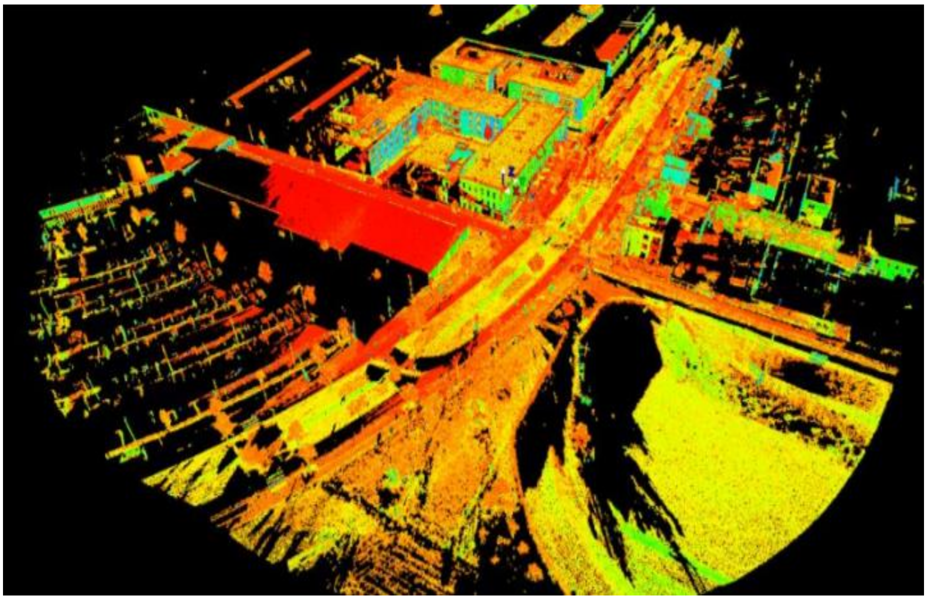


Figure 12: Existing building and environment (scan)

There are particular site demands for every prefab construction process; in this case the existing flat roof insulation will have to be removed before the new construction can be placed. Furthermore, logistics are demanding as prefab components have big dimensions and a comparably high own load. The construction process is depending on stable weather conditions and the new storey will be erected while all the business activities of the tenants in the existing building take place. Therefore, there is a strong need for a very swift construction process in order to minimise sound disturbance and the risk of water ingress. The rooftop construction will be consisting of lightweight prefab wall panels for high thermal performance and sound insulation. The walls and the new roof will be mounted on a primary steel construction. The time frame of the realisation depends on weather conditions as the existing sealing has to be removed and a new sealing has to be established as soon as possible.

The late spring of 2018 was pre-identified as the appropriate time for this critical action facing the risk of causing damage on the existing stock.

The envelope of the rooftop extension was planned to be finished in 4 weeks as it is planned as a turnkey project it will be handed over after 3 to 4 months.

Caused by external influence the Cologne rooftop extension will not be realized until the end of the INSITER project. Nevertheless all measuring and testing activities assigned to the use cases - QR code scanning, AR application and 3D laser measurement including deviation analysis- have been realized on site and at the factory already and documented below.

In January 2018 the owner of the building signed a contract with a private company based in Hürth, a city nearby Cologne. The nature is a real renting contract starting in October 2018. The purpose of the contract is a realisation of approximately 350m² of space used for a ward for agrypnocoma patients. The building permission was based on this use and the space assigned to the tenant mentioned ahead is making the investment of the extension profitable. In March 2018 the tenant approached the owner and informed him that the refinancing basis in the care taking system has been changed tremendously causing lower profit. The insurances changed their demand for the built environment for agrypnocoma take care, larger rooms and additional spaces are needed causing extra costs. We tried to encourage all partners to speed up but the final permission of the care insurance companies is still pending and it is expected that the clarification will be done in the next two months. However, this is too late as we have a preparation period of three extra months caused by very well running prefab construction industry in Germany.
Nevertheless as mentioned above all tests related to use cases have been performed at highest level on site. Additionally some tests have been done at factory level of the assigned general contractor for this project. Based on the produced BIM data at HOCHTIEF Vicon the deviation analysis has been performed in accordance with the collected on site 3D laser scanning data.

However, as the defined use cases are related to simulation of effects all needed data has been harvested already to analyse the use cases and balance the results against quality expectations that are related to the INSITER quality descriptions. The details are embedded in D1.2 Guidelines for self-inspection in new construction and D1.3 Guidelines for self-inspection in refurbishment and related to measurement processes described and qualified in D1.5 Measuring and diagnosis solutions for inspecting building components and D1.7 Measuring and diagnosis solutions for inspecting MEP/HVAC components and scientifically applied at laboratory level at D5.1 Lab test protocols and set-up and D5.2 Lab test report and recommendations. The needed testing and the correlated results have been performed at factory level at the general contractor's premises.

Within the INSITER project the measurement procedures have been scientifically surveyed intensively. This analysis was following the applicability of tools in different surroundings. In WP5 the demonstration activities are developed related to practical application performed on site and supported by experts if needed. The scientific approach and analysis at the early development stage is now overlaying the practical application and the nature of this type of application is different. The easy use of tools by workers on site with a non-scientific background demands other additional very practical balancing systems. This is the reason why we chose the FMEA methodology as an evaluation tool for the Cologne case and the methodology might be used again for D5.7 Cross-case analysis and benchmarking

The analysis of test results for the three established uses cases: Scan of QR code, Geometry check of the ground sill and AR application has been performed using this evaluation tool that is well introduced in product development processes at industry level but is currently rarely used in the building sector.

Severity	Frequent (4)	Occasional (3)	Uncommon (2)	Remote (1)
Catastrophic (4)	16	12	8	4
Major (3)	12	9	6	3
Moderate (2)	8	6	4	2
Minor (1)	4	3	2	1
	Probability			

KEY
- Must Take Action (red)
- Should Take Action (orange)
- No Action Required (yellow)

Table 7: FMEA criticality matrix

The methodology applied in quality engineering processes is called FMEA (Failure Mode and Effect Analysis). The FMEA is based on the assumption that at early phases of development processes for new products or processes there is at least a clear picture of the developers of what the ambition of the project is and what the expected final results of the project are or what the enhanced process performance of the yet to be developed solution will be.

Using a scenario technique focusing on the new features planned to be available in the future after the project has successfully ended, the possible errors that might occur while applying the new INSITER tool are collected and their influence on the performance quality are weighted by two factors: 1. How is the estimated probability of this construction error to occur? 2. How big is the influence on the expected technical and/or process quality level if the failure occurs? These two factors are multiplied and build the criterion that is called risk factor. The next step is to analyse how the probability of the occurrence can be reduced -if it is valuable and necessary at it has an important risk factor- by means of proactive care taking or how it can be totally avoided.

2.3.2 Use Case 1: Scan of QR code

Additionally to the generic description in deliverable D5.3 of the Demo Case 1 for the Health Care Centre, Cologne, the descriptions in D5.4 Field validation report and recommendations refer to a more functional definition of the now precisely defined use case of QR code scanning related to life testing activities and the validation of the INSITER methodology. This description of the detailed process steps from scanning a QR-code on site -after having assigned a QR-code already in the BIM model- to the retrieval of information coming from a BIM model serves as a base for developing the required functionalities. In D5.5 the processes of data exchange and application using the INSITER tool are analysed in terms of their quality and creation of impact focusing on the application.

The use case QR code scanning is a functionality embedded in the second step of INSITER´s eight step methodology, which is referring to “Checking of Components”. It is intended to validate the correctness of the delivered prefabricated component on one hand and on the other hand it will provide information to the site team about where to install and position the delivered component. Furthermore, the technical data are assigned and the components can be identified.

INSITER D5.4; data sheet use case					
Use Case 1.1		**Scan of QR code**			
Relevant Demonstrator		Health Centre Cologne			
Responsible Insiter Parter		3L			
	description	responsible partner	additional input	time schedule	tools to be used
Step 1	create BIM Model	3L/HVC	Panel producer	done	IFC viewer
Step 2	upload BIM to server	HVC	n.a	done	n.a.
Step 3	production of panels	3L, panel producer	n.a	contracted	
Step 4	inform site of date panels will be ready	3L, panel producer		pending	
Step 5	upload all relevant information to server	3L, panel producer			INSITER guidelines
Step 6	transportation of panels to site	panel producer	transport company		
Step 7	scan QR code	assembler			QR code scanner
Step 8	check and report quality of panels	assembler			INSITER software tool

Table 8: data sheet use case 1.1

The three important follow up process steps related to the origin QR code scanning procedure identified in D5.4 are:

- Step 1: Scan the QR code on the delivered component
- Step 2: Identify the specific component within the available BIM model
- Step 3: Retrieve information

The following images will provide a deeper insight into these three process steps:

Step 1

Select the menu item Product identification and in the camera panel at the right side aim for the QR code on the delivered construction part. The QR code will be scanned and translated into a specific element GUID for further data assessment.

Figure 13: Screenshot

Step 2

When recognized the App will show the model and highlight the part that correspond to the GUID derived from the QR code. This will provide information about the correct planned location to the site team, where this specific component has to be installed.

Figure 14: Screenshot

Step 3

Click on the highlighted construction part and all information related to that part (documents, checklists, images, videos) become available. All related data, which is available on INSITER´s SharePoint site regarding this element, will be provided to the site team for further processing. The QR code scanning is an easy-to-use functionality on one hand and provides all required information to the site team, which makes the tool at the same time very powerful.

Figure 15: Screenshot

The QR code scan is a well introduced methodology. The location of the component and its characteristic features supports the quality assurance process in all phases of the components' life cycle: from modelling to prefab quality check and from site positioning to maintenance issues.

Possible failures

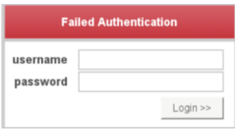
QR code scanning is not successful

1. No power

2. Hardware defect

3. Software defect

4. Bad handling by the applying worker (incorrect login/wrong login data)



5. No/not an appropriate internet connection

6. Wrong QR code attached to component at factory

7. Server providing BIM model is down

The QR code scanning is a functionality provided by the RE Suite, which is part of the INSITER´s toolset. Before performing a Scan the user has to open the software on a tablet and login to the system with his personal login data.

Probability of occurrence

1. No power, Possible, great influence, second device will secure the scanning, low risk
2. Hardware defect, Possible great influence, second device will secure the scanning, low risk
3. Software defect, Possible, middle influence, continuous online monitoring and bug fixing, low risk
4. Bad handling by the applying worker (incorrect login/wrong login data), Possible great influence, middle risk, awareness training is needed and training on the job
5. No/not an appropriate internet connection, Possible, great influence, third party dependency, alternative data transfer possible?
6. Wrong QR code attached to component at factory, Possible, great influence, middle risk, awareness training is needed and training on the job, a four eye check system is needed at factory level
7. Server providing BIM model is down, Possible, middle/high influence, establish second source solution, low risk

The methodology check is assuming that the panels delivered are perfect. The QR code scan creates an inventory of the delivered prefab panels. The inventory of checked in panels on site can be checked online with the full set that left the factory in order make sure if every component that was delivered from the factory reached the site.

The possible quality gaps are related to this „being perfect“ assumption. Typical building site logistics as cranes are needed to transport large scale prefab panels smoothly. The load bearing structure of the panels is stressed not just with the regular bearing load but with the bigger and dynamic logistic load. The problem is the that the load bearing case „logistic“ is crucial. It might be possible that the structure is internally stressed exceptionally and harmed by inappropriate handling. This is not necessarily visible for typical visual inspection as cracks are not regularly visible at the surface of the component if the element has a flexible finish e.g. by a thermal insulation system. There is an urgent need - especially if third parties are involved- that the delivery and the site logistics are monitored at highest level to avoid high influencing construction errors caused by envelope inconsistencies and air leakages and embedded thermal insulation dislocation.

Quality expectations

The last minute and final check before mounting on site has to be performed to be sure that the right panel is delivered and securely arrived at the site, it is foreseen to be mounted at the right place i.e. the positioning and the quality of the panel -structure, building physics, other features- is correct and checked. Possible quality problems are: not the right quality at the right place, wrong element related to the efficient mounting recess follow up, wrong positioning, follow up damage as the on-going mounting is almost not revertible, extra logistic cost and bad performance of the building in terms of energy consumption.

Influence on quality level

1. No power, possible, great influence, second device will secure the scanning, low risk, influence on quality is minimised

	high risk	middle risk	low risk
great influence			x
middle influence			
low influence			

2. Hardware defect, possible great influence, second device will secure the scanning, influence on quality is minimised

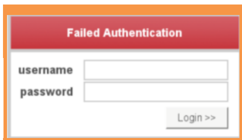
	high risk	middle risk	low risk
great influence			x
middle influence			

low influence			

3. Software defect, possible, middle risk, continuous online monitoring and bug fixing, low risk, influence on quality is minimised

	high risk	middle risk	low risk
great influence			
middle influence			x
low influence			

4. Bad handling by the applying worker (incorrect login/wrong login data), Possible great influence, middle risk, awareness training is needed and training on the job, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

5. No/not an appropriate internet connection, possible, great influence, third party dependency, alternative data transfer possible, middle risk, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

6. Wrong QR code attached to component at factory, possible, great influence, middle risk, awareness training is needed and training on the job, a four eye check system is needed at factory level, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

7. Server providing BIM model is down, possible, middle/high risk, establish second source solution, influence on quality is high.

	high risk	middle risk	low risk
great influence			x
middle influece			
low influence			

2.3.3 Use Case 2: Geometry check of the ground sill

The process description is already done exhaustively in D5.4 thresholds and KPIs have been listed as samples. The demonstration site in Cologne was analysed by a 3D laser scan in order to check the geometry and make sure that a balance of the results against thresholds is possible and means to improve if necessary might be developed by the mounting team.

The geometry check of the existing ground sill produced on site against the modelled ground sill is easily done. The first step is the 3D data collection of the existing concrete structure poured in place or just placed if it is consisting of prefab components. This is done with a regular 3D laser measurement system. The captured data will be analysed by the RE Suite to check the collected data against the idealistic out of failure BIM model. The clash detection action is producing a report focusing on “as modelled” deviations.

The data survey embedded in the RE Suite is checking not just deviations but additionally and even more important the significance of the deviations related to:

1. Size, Dimension
2. Geometrical accuracy to angular alignment
3. Geometrical accuracy to flatness.

INSITER D5.4; data sheet use case				INSITER INTUITIVE SELF-INSPECTION TECHNIQUES	
Use Case 1.2		**geometry check of the ground sill**			
Relevant Demonstrator		Health Centre Cologne			
Responsible Insiter Partner		3L			
	description	responsible partner	additional input	time schedule	tools to be used in site testing
Step 1	Preparation and Retrieval of latest IFC BIM Model	HVC	3L, Panel producer	BIM model available	IFC viewer, INSITER RE suite
Step 2	On- site examination	HVC, 3L		At the beginning of construction work (March 2018)	3D laser scan
Step 3	Clash detection	HVC, DEMO	3L	March/April 2018	IFC viewer, INSITER RE suite

Table 9: data sheet use case 1.2

Possible failures

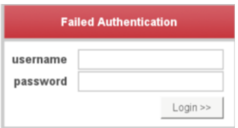
3D laser scanning is not successful

1. No power

2. Hardware defect

3. Software defect

4. Bad handling by the applying worker (incorrect login/wrong login data)



5. No/not an appropriate internet connection

6. Wrong measures taken

7. Server providing BIM model overlay and storage is down

The thresholds in the different categories depend on the prefab system and the characteristic provision of means to cover tolerances in the above mentioned categories. The thresholds will differ from prefab system to prefab system. Deviations at ground sill level are producing on-going and often increasing deviations especially if the building has more floors. In that case the existing and acceptable tolerances are not just dependent on the ground sill but the accuracy is influenced by the number of floors, too. The thresholds can be adjusted at the RE Suite to fit these different demands of clash detection. The figure below is a sample for a threshold overview related to a German DIN norm. A similar table with adjustable threshold is embedded in the RE Suite.

limiting deviations for angular misalignment DIN 18202								
	nominal sizes ≤ 0,5 m	nominal sizes >0,5 m and ≤ 1 m	nominal sizes >1 m and ≤ 3 m	nominal sizes >3 m and ≤ 6 m	nominal sizes >6 m and ≤ 15 m	nominal sizes >15 m and ≤ 30 m	nominal sizes >30 m and <60 m	
floor surfaces, ceiling surfaces, wall surfaces surfaces in stage, surfaces of building elements	3 mm	6 mm	8 mm	12 mm	16 mm	20 mm	30 mm	

Table 10: Limiting deviations for angular misalignment according to DIN 18202

Figure 16: 3D laser scan equipment

Probability of occurrence

1. No power, Possible, great influence, second device will secure the scanning, low risk
2. Hardware defect, Possible great influence, second device will secure the 3D Laser scanning, low risk
3. Software defect, Possible, middle risk, continuous online monitoring and bug fixing, low risk
4. Bad handling by the applying worker (incorrect login/wrong login data), Possible great influence, middle risk, awareness training is needed and training on the job
5. No/not an appropriate internet connection, Possible, great influence, third party dependency, alternative data transfer possible?
6. Wrong job description for the 3D laser scanning company, Possible, great influence, middle risk, explicit job description is needed and training on the job
7. Server providing and overlaying BIM model is down, Possible, middle/high risk, establish second source solution

The collection of data - see step 2 in the use case chart in table 3 - is done with regular 3D laser scan equipment that shares the data with the BIM model for performing clash detection and creating the clash detection report.

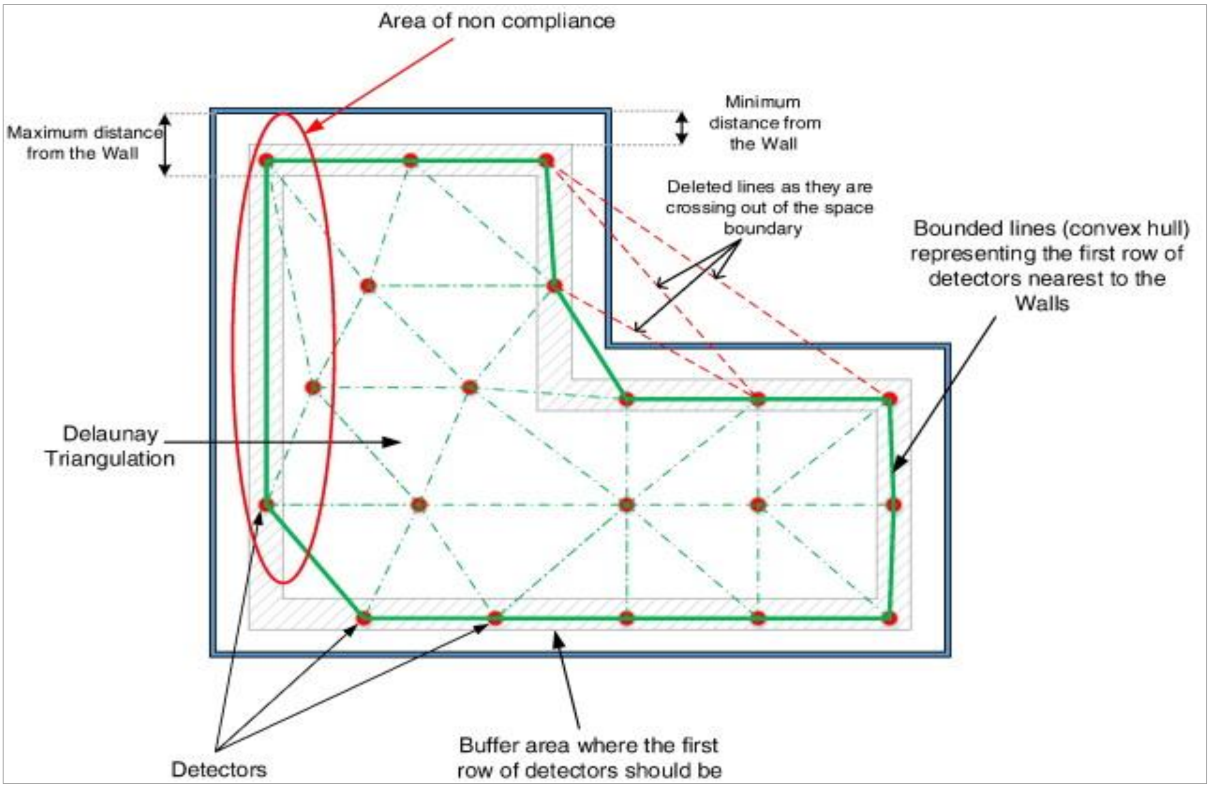


Figure 17: Sample of a deviation overview created as one chart of the clash detection report and shown in the RE Suite

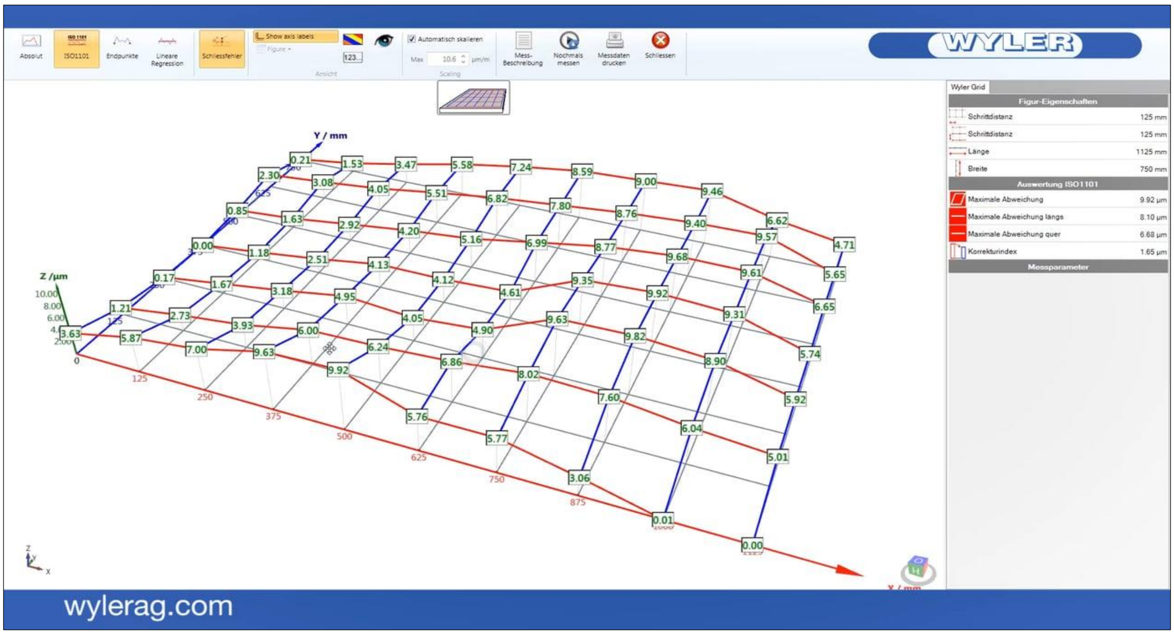


Figure 18: Sample of the 3D overview of the ground sill with deviations provided by a grid and shown in the RE Suite

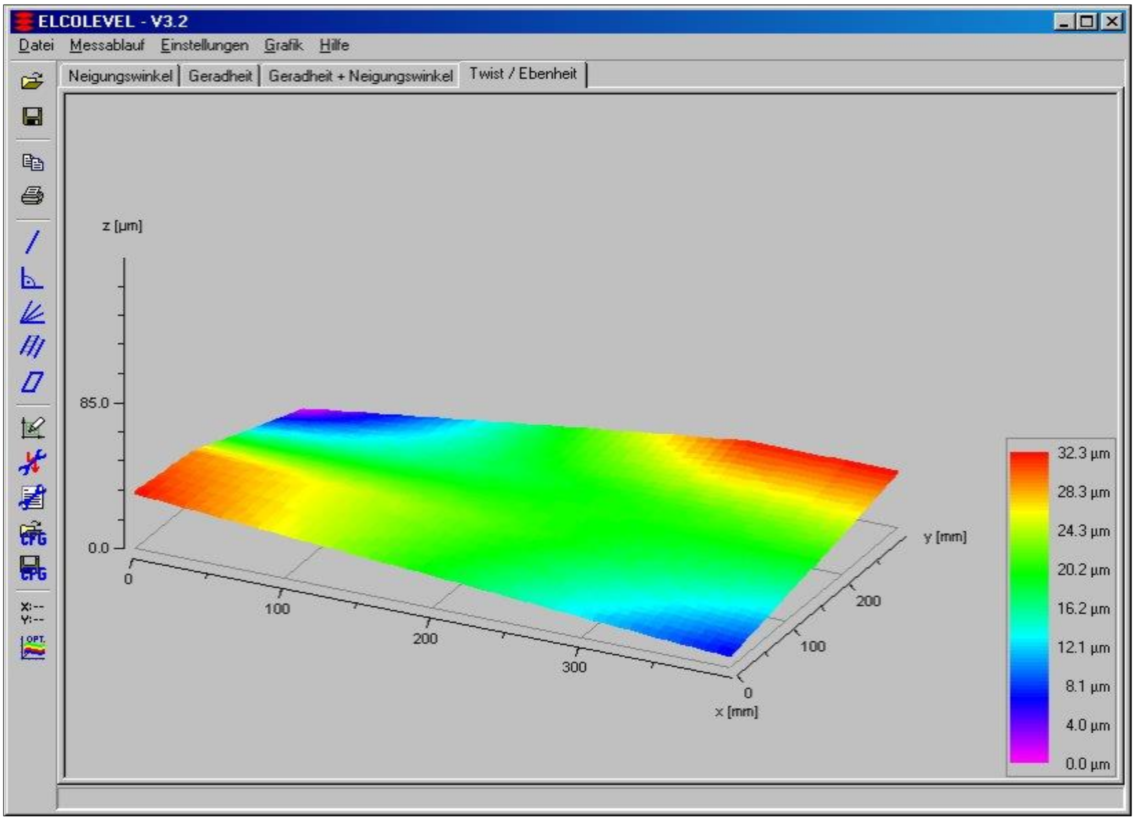


Figure 19: Sample of a deviation analysis related to areas

The threshold of the deviation analysis will differ following the characteristic needs of the applied building system and the solution offer created by the contractor. Therefore the RE Suite is designed as an open and adjustable framework under flexible thresholds that will be inserted by the applying users following the systemic needs of the applied system.

Quality expectations

Final check before mounting on site to be sure that the tolerance thresholds are kept. Possible quality problems are: thresholds are not kept, follow up damage as the on-going mounting is almost not revertible and tolerances add up, extra logistic cost and bad performance of the building in terms of energy consumption.

Influence on quality level

1. No power, possible, great influence, second device will secure the scanning, low risk, influence on quality is minimised

	high risk	middle risk	low risk
great influence			x
middle influence			
low influence			

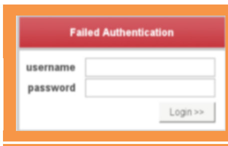
2. Hardware defect, possible great influence, second device will secure the scanning, influence on quality is minimised

	high risk	middle risk	low risk
great influence			x
middle influence			
low influence			

3. Software defect, possible, middle risk, continuous online monitoring and bug fixing, low risk, influence on quality is minimised

	high risk	middle risk	low risk
great influence			
middle influence			x
low influence			

4. Bad handling by the applying worker (incorrect login/wrong login data), Possible great influence, middle risk, awareness training is needed and training on the job, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

5. No/not an appropriate internet connection, possible, great influence, third party dependency, alternative data transfer possible, middle risk, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

6. Wrong measures taken, possible, great influence, middle risk, awareness training is needed and training on the job, a four eye check system is needed at factory level, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

7. Server providing BIM model is down, possible, middle/high risk, establish second source solution, influence on quality is high

	high risk	middle risk	low risk
great influence			x
middle influence			
low influence			

As designed and as built deviation analysis and quality check

Additionally to the regular geometrical deviation analysis taking into account the characteristics of the existing building site and the interference effects at building component level a deviation quality check focusing on geometrical deviation at component level has been performed. This is possible as checking the modelled version and idealistic positioning of the building components at least against the deviation thresholds given by the component producer or supplier e.g. of embedded windows is done as an overlay of two model versions checking the difference between the modelled and the existing version.

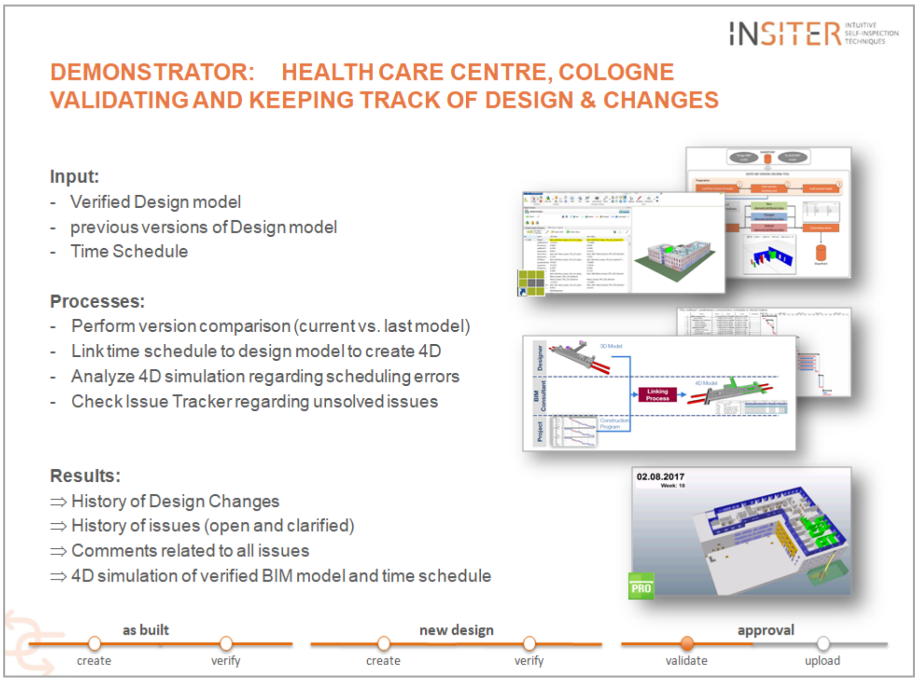


Figure 20: Track of design and changes

The existing building environment is providing the most critical influence on geometrical inconsistencies that cause adding up tolerance problems. To identify the critical errors and qualify the identified deviations a cross check is easy to perform and delivers the data needed to prepare a qualified decision on site following easy decision making criteria. For an example good enough, possibly to be changed –taking into account influences on neighboured pre-fab panels or joints of panels or joints of panels with the existing building structure- or definitely to be changed criteria have to be precisely defined. This process of identification has been exemplary performed and analysed at the Cologne site.

The input needed is the verified design model and the previous versions. Based on a time machine approach –like done in intelligent back-up systems for data storage- the difference between the models can be identified based on the time level assigned to the different versions related to their adjustment. The output is an inventory recording the history of design changes caused by the influence of positioning the components on site. As the time related data are integrated in the as designed survey this data material can be named as 4D BIM model data.

Process Sub-Step	System	Description	Output / Follow-Up Actions
1	Sharepoint	BIM-Modeller checks the availability of the "Design BIM"-model and the "As-Built BIM"-model In case those files are not available to the BIM-modeler: Download both versions of the model from SharePoint.	"Design BIM"-model and "As-Built BIM"-model are available to the BIM-Modeller.
2	Desite MD	Preparing the Version comparison: 1. Load "Design BIM"-model, 2. Start version checking tool and 3. Add "As-Built BIM"-model.	Models now are integrated to the Version Checking Tool
3	Desite MD	Decision which information should be compared: - Geometry: dimensions of elements, - Coordinates: position of elements - Attributes: attributes itself and values of attributes	Colored model, showing the changes: - new elements - changed elements - deleted elements
4	Desite MD	Generation of a list of adjusted objects or specifications based on the comparison between "pre-built BIM" and "as-built BIM"	Generated report as excel or pdf document or stored in a database. Will be uploaded to INSITER Server
5	SharePoint	Upload of report on share point to show all participants	

Table 11: Process sub-steps for version comparisons

A deviation report is showing the differences in terms of geometrical deviation of positioning and orientation at component level based on the above mentioned site interferences.

The tools used to analyse the time wise data are a storage set up provided by the share point and the Desite MD software. The flow chart attached shows the follow up steps and generated output data. The BIM model shows the deviations in coloured versions for easy identification even at handheld level provided by an IFC viewer. The onsite check closes with producing the check lists of deviation as an EXCEL chart and a PDF document enabling the documentation and discussion of the results at different user level and is realised in order to decide about needed interventions and actions or acceptance of the built situation.

Conclusion

The geometrical deviation analysis checking the differences in angles and dimensions are influencing the density of the envelope quality at high level. As the pre-fab components are assumed as being perfectly produced in INSITER and the as designed quality check - e.g. focusing on geometry, material choice and appropriate application, sealing of critical areas as joints with embedded building components and pre-calculated performance data compliance of thermal inertia moment or sound absorption- at the factory is performed at the highest level, air leakages are causing the biggest problems and the reason for consuming more energy than calculated at design model stage.

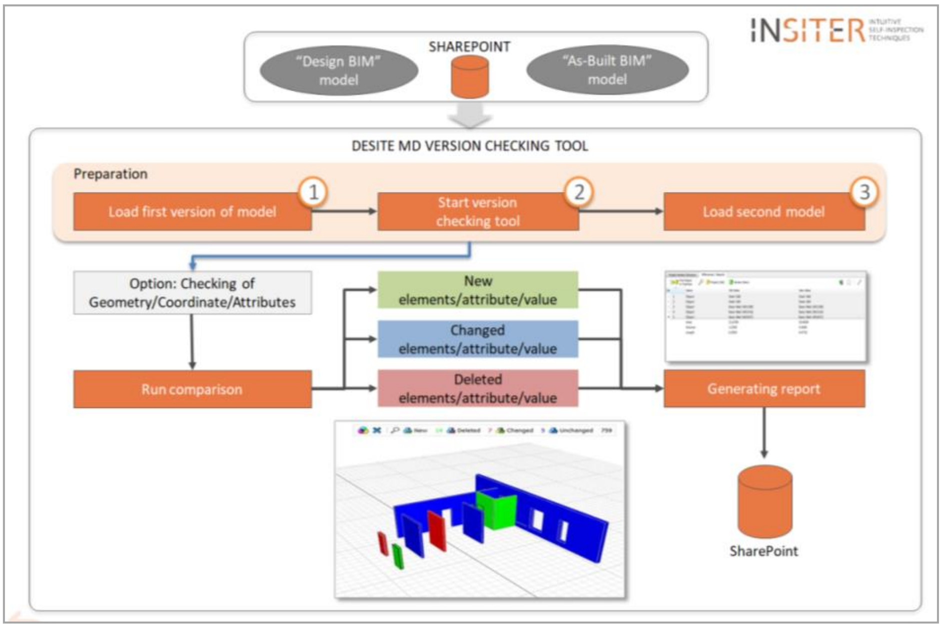


Figure 21: Scheme version comparisons

Closing the gaps between panels is the most important activity to avoid thermal losses. Therefore the geometric deviation analysis at building component level is closing this quality gap by taking care that the building system related tolerances are kept. Furthermore the deviation analysis at component level as described above assures that geometrical deviation is recorded at building level and if the influence of this deviation is passing the thresholds or probably passing the defined thresholds appropriate interventions can be applied. As the different versions related to the time oriented 4D BIM model check are recorded the analysis is identifying the influence at crucial stage as a learning system creating an early warning alert based on experiences and lessons learned.

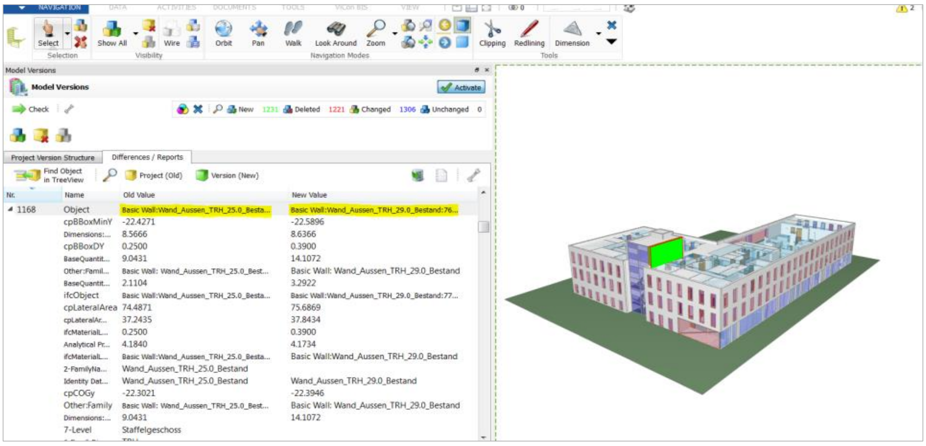
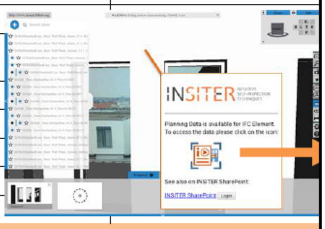


Figure 22: Screenshot version comparison with table overview

2.3.4 Use Case 3: Application of Augmented Reality



INSITER D5.4; data sheet use case				
Use Case 1.3		**Application of AR**		
Relevant Demonstrator		Health Centre Cologne		
Responsible Insiter Partner		3L		
	Description	responsible partner	additional input	tools to be used in site testing
Step 1	Preparation and Retrieval of latest IFC BIM Model	HVC and FhG	3L, Panel producer	IFC viewer, INSITER AR
Step 2	On- site examination	3L	FhG, partners on site	n.a.
Step 3	Set up of AR tracking system	3L, FhG	partners on site	INSITER AR
Step 4	Application of AR to verify the assembly location of BIM elements	3L, FhG	partners on site	INSITER AR
Step 5	Application of AR to evaluate built-in elements and installed components	3L, FhG	partners on site	INSITER AR

Table 12: Data sheet use case 1.3

In addition to the description in D5.4, the application of the INSITER AR solution on-site has been analysed and checked against quality expectations. During the construction the AR application will is applied by the architect and construction engineers with focus on the construction consistency of dedicated building elements and prefabricated panels.

Main Steps concerning the application of the BIM based Augmented Reality with the INSITER AR Vision App app are:

- Guidance and verification of the assembly location and placement of
- BIM elements;
- Evaluation of BIM-based built-in elements and installed components concerning construction errors and inconsistencies;
- Access of referenced planning information on INSITER share point.

The INSITER BIM based Augmented Reality application has been developed and the access of referenced planning information on INSITER share point has been demonstrated (see also deliverable D2.2).

During the application of the developed INSITER AR solution for extensive and complex 3D models including BIM and referenced planning data (e.g. instruction manuals), the actors on-site can access and visualize related BIM objects superimposed to the real construction environment. Therefore, the AR computer vision based tracking system is set-up, by applying reference markers within the BIM model and the real environment.

Implemented computer vision based tracking algorithms for multi-marker and enhanced model tracking, along with extensive and complex BIM AR visualization functionalities and data reference system are provide a comprehensive and interactive AR BIM data visualization solution for INSITER and the AR use cases.

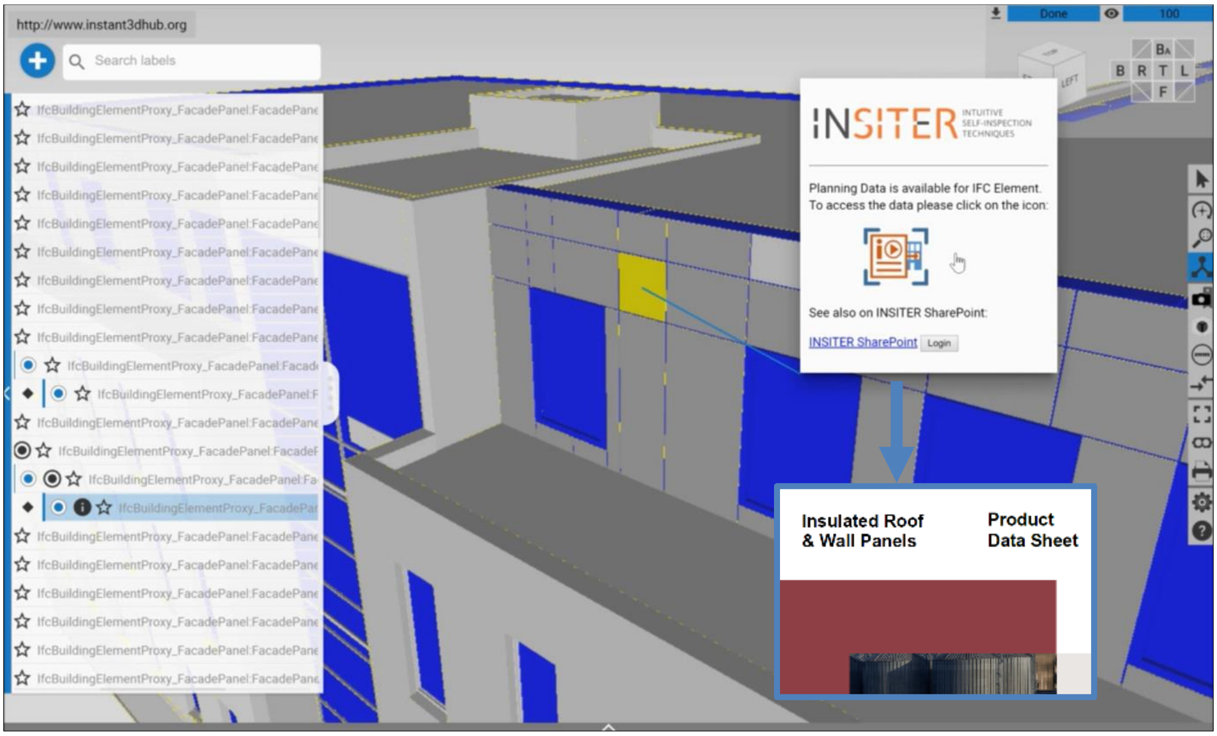


Figure 23: INSITER AR Vision App screenshot - exemplary BIM element selection of facade element cornering the INSITER Use Case Demo in Cologne with access to referenced planning data

The AR application of the INSITER AR solution for the scheduled Cologne demonstration activities have been performed at factory and building level at Fraunhofer IPA in Stuttgart, as the Cologne Construction activities have not been started yet.

One scheduled main task the AR application can support, is the verification of assembly locations and placement of BIM elements, by selecting a dedicated panel or facade elements cornering on-going construction work.

Within a second step, the already built-in elements and installed components and BIM elements can be evaluated and their correct position and assembly can be verified in detail with the help of AR as illustrated in Figure 23. Thus, construction errors and other inconsistencies can be identified by combining the on-site real work environment and as-is state with actual digital planning information and the BIM target state.

Besides BIM IFC 3D-models and model parameters, further planning data provided by partners via the INSITER SharePoint can be accessed. This data includes planning documents for dedicated building and façade elements for multiple stakeholders and construction engineers on-site.

As already described in D5.3 and D5.4, the overall performance of the developed AR application was evaluated along with on-site tests at factory level and on construction sites with construction workers and the implemented computer vision based tracking technology has been tested successfully.

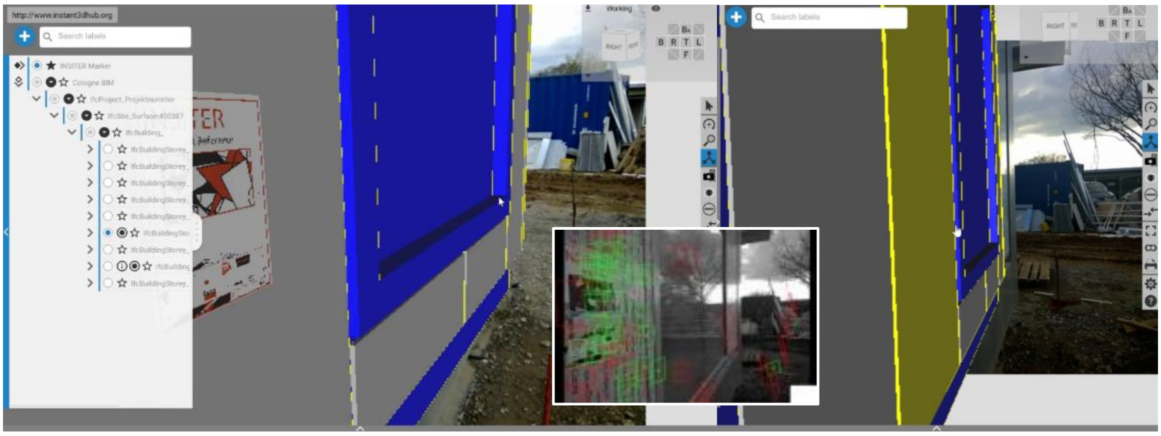


Figure 24: INSITER AR Vision App screenshot - exemplary BIM element evaluation concerning on-site extended tracking of BIM elements and installed components in AR

As already presented in Ancona at M24 at lab level the AR application is feasible and attractive to construction workers. The qualified closing of the gaps between the prefab components is one of the most critical steps for creating a dense building envelope. The AR applications are helping to assure this important part of quality assurance on site.

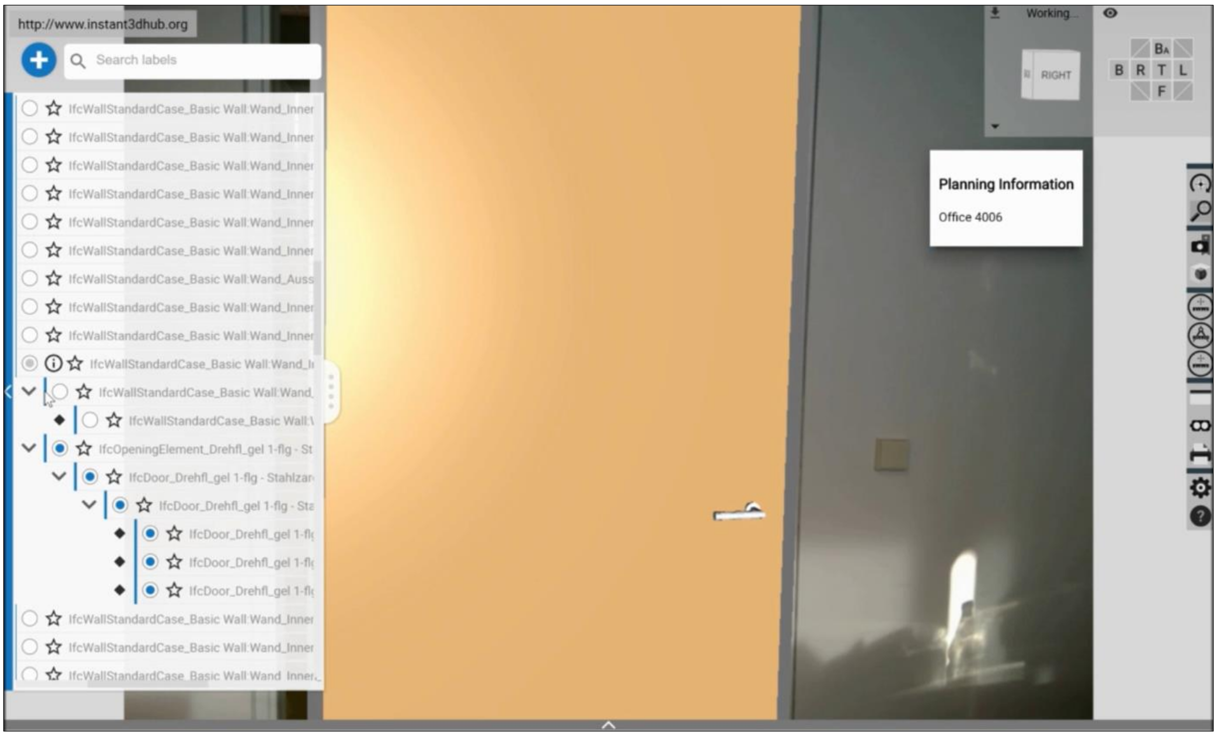


Figure 25: INSITER AR Vision App screenshot - exemplary BIM element evaluation concerning built-in elements and installed components (door example)

Besides the visualization of BIM models with the INSITER BIM based Augmented Reality tablet application also the INSITER HoloLens BIM-based Mixed Reality App has been applied and demonstrated off-site for Cologne BIM data, as the construction site has not been available. With the help of the INSITER HoloLens BIM-based Mixed Reality App, BIM data and information can be visualized within different scale level in AR, providing for any stakeholder the overview of the building and constructions site up to the real size of the building object (see also deliverable D2.2 and the Figure 26.).

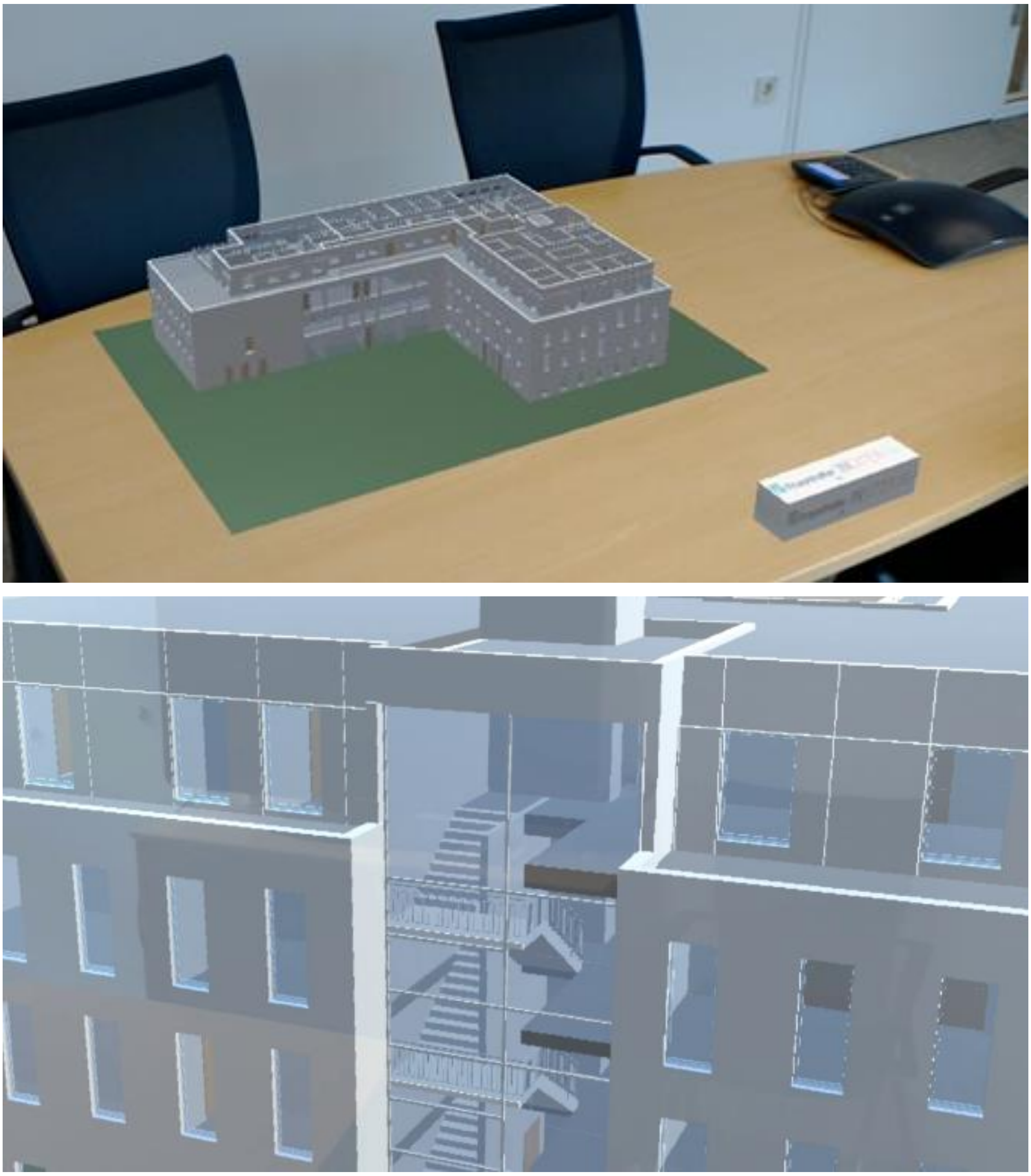


Figure 26: INSITER HoloLens BIM-based Mixed Reality App screenshot - visualization and evaluation of BIM models on HoloLens on different scale levels with Cologne BIM data

Quality expectations

Guidance for workers on site for identifying components and locate them accurately (these issues have been described already in the chapter about QR code scanning, as the process is almost the same but with another quality assurance topic), in terms of positioning of panels, the mounting is visualized and additional back-up information is available to smooth the process from the perspective of the involved workers

Furthermore the error checks and risk analysis are influenced by the same error list that was ready developed for use case 1 QR code scan.

Influence on quality level

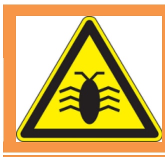
1. No power, possible, middle influence, second device will secure the AR process, low risk, influence on quality is minimised

	high risk	middle risk	low risk
great influence			
middle influence			X
low influence			

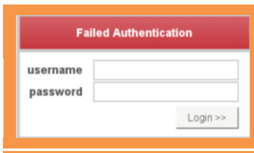
2. Hardware defect, possible great influence, second device will secure the AR process, influence on quality is minimised,

	high risk	middle risk	low risk
great influence			X
middle influence			
low influence			

3. Software defect, possible middle influence, continuous online monitoring and bug fixing, low risk, influence on quality is minimised

	high risk	middle risk	low risk
great influence			
middle influence			x
low influence			

4. Bad handling by the applying worker (incorrect login/wrong login data), Possible great influence, middle risk, awareness training is needed and training on the job, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

5. No/not an appropriate internet connection, possible, great influence, third party dependency, alternative data transfer possible, middle risk, influence on quality is high

	high risk	middle risk	low risk
great influence		x	
middle influence			
low influence			

6. Wrong QR code attached leads to wrong AR program, possible, great influence, low risk, awareness training is needed and training on the job, a four eye check system is needed at factory level, influence on quality is high

	high risk	middle risk	low risk
great influence			x
middle influence			
low influence			

7. Server providing BIM model is down, possible, middle risk, establish second source solution, influence on quality is high.

	high risk	middle risk	low risk
great influence		x	
middle influece			
low influence			

2.4 Conclusions

The key to a basic quality assurance is closely connected to the right positioning of the prefab elements. The durable closing of the gaps and the correct joint is assuring that no risky air leakages are occurring as the gaps between the elements are not closed. It is important to make sure that the tolerances for mounting are kept. Therefore it is necessary to focus at the preparing works that are covered by third parties that are in charge for the biggest problems on prefab sites as Prof. Dr.-Ing. Girmscheid from ETH Zürich states in his publication about industrialised building methods. The right positioning and the quality check of the element itself minimizes the risk of air leakages up to 50 % based on assumptions deducted of experiences of prefab building sites. The pre-set of the individual building system defines the tolerance thresholds and the key indicators have to follow these values.

3. Real demonstration case of new construction in Delft, NL

3.1 Changes compared to the original plan described in D5.3

At the time that D5.3 was issued, the Delft demonstration case was quite new. The first ideas were field demonstration activities with a focus on the positioning of the building elements with the help of QR codes, the testing and inspection of air tightness measurement on site and digital VR instruction including dimensions and tolerances facilitating assembly on site. When more in depth knowledge about this demonstration project was gathered, we adjusted the use cases to the following use cases:

- Use Case 1: Comparison of the IKEA-like self-instruction manual with the actual situation on site
- Use Case 2: Identify right moments for visual inspection and inspection with equipment
- Use Case 3: Compare the as-designed situation with the as-produced and as-built situation

The first ideas were incorporated in the use cases as defined in D5.4. In use case 2 we put the focus on air tightness as already mentioned in D5.3. The use of AR for self-instruction is taken into account. For a relative simple task of mounting prefab elements the use of AR did not have an added value.
In D5.3 we only took the Office Lab Building into account. But we decided to use also the Living Lab Building for input.

3.2 Field validation / demonstration procedures for each use case

Introduction

In D5.3, the description of the site characteristics of this demonstrator was given, next to the definition of the selected use cases for the purpose of field validation. The construction of two new test beds by Sustainer Homes at The Green Village: the Office Lab and the Living Lab, function as a demonstrator for INSITER. Both buildings consist of CNC-produced wooden modules that have been assembled on-site and its structure has already been completed. The construction is made ready for placing the installation on site. The Office Lab is used daily based on its function, while the Living Lab (in collaboration with DUWO: student housing corporation) is currently inhabited by 2 students. As a brief summary, both structures together with a short description of them and the scope of the INSITER field validation activities within Task 5.2 are presented below:

- Office Lab

Description: The building is an office space supporting research and innovation activities while being flexible, adaptable and modular to be used as a test bed: so that different parties can install and research their innovations. The office space is used since June 2017 by real users, assuring that innovations are subject to actual usage, consumptions and feedback. The office Lab is in total 250m^2 and can accommodate up to 20-25 employees.

Figure 27: Office Lab building Green Village Delft

The scope of the field activities related to the Office Lab focused on the validation and applicability of the INSITER methods and tools based on on-site findings. The key questions refer to the feasibility of the proposed self-instruction and self-inspection techniques and the use of the INSITER-methodology in practice.

- Living Lab

Description: The building will be used as a testbed in which all kinds of innovations related to the living environment, can be researched while being inhabited by real students. The intention is to create an actual living lab for sustainable innovations, where students are actively involved. The main target group living in the first two apartments are TU Delft students: that have moved in the first weekend of October 2017.
The scope of the field activities has the same focus as the one of the Office Lab. The added value of these refer to: 1.the anticipation of the assembly demands with respect to the second floor (Office Lab is a single-floor building); and 2. the elaboration of the replicability of the findings from the Office Lab, as the adaptable and modular character of Sustainer Homes approach, next to the common location of both projects gave us such an opportunity.

Figure 28: Living Lab building Green Village Delft

Our endeavor refers to the understanding of the demands of such construction, based on observations and live feedback through the interaction with the involved parties. We use these insights as a basis for the composition of the theoretical validation of the INSITER methodology and tools according to the on-site construction related anticipations. The inherent character of such a construction, together with the requirement of our stakeholder for quality assurance during mounting with respect to air-tightness, pointed out as main areas of interest the joints of the modules. As it has already introduced in D5.3, an IKEA-like instruction manual produced by Sustainer Homes is used to facilitate mounting.

A forward of the on-site situation for both buildings is given below:

- Office Lab

As typically happens on a construction site, a dynamic situation was faced. This pointed out the necessity of a holistic methodology that guarantees the sequence of the workflow and assures quality during construction. The Office Lab consists of in total 16 modules, while due to the weight of them; workers frequently put some extra effort into the proper assembly, which was tiring: increasing the risk of negligence. To secure the proper (airtight) connection of the modules and avoid damages during transport, the semi-closed structure foam tape (Celdex Panelseal) between the elements was applied on site.

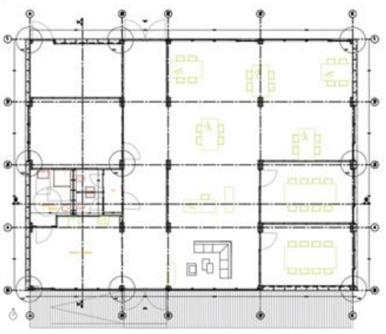


Figure 29: Floor plan Office Lab

- Living Lab

The Living Lab consists of 4 modules in comparison with the 16 of the Office Lab. That made the assembly process smoother and faster, together with the good weather conditions during the days of the mounting. Living lab has a fire protection layer on the roof of the first floor, for the fire safety of the students. An interesting additional instruction that was given to the assembly workers with respect to air tightness is that this time they had to stick the water-proof foil layer with airtight tape. In terms of usability and applicability of such a software solution as INSITER investigates, issues as the accessibility of the instruction manual and the checking of the construction details will have been smoother, if such a mean was available.

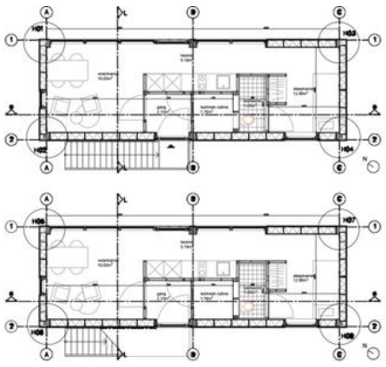


Figure 30: Floor plan Living lab (2 floors)

The following sub-chapters describe the three selected use cases for the Delft demonstrator of D5.3, to discuss if they can really be tested on site. This can be seen as a validation through the field experience that brings together, on a theoretical basis, different developed tools and methods during the INSITER timeline.

3.2.1 Use Case 1: Comparison IKEA-like self-instruction manual with actual situation on site

The context: The main focus of this use case is on how the INSITER methodology and software toolsets fit in the mounting process of the prefab modules. Here we discuss the implementation of "self-instruction" within STEP 7 (self-inspection during construction), following the relevant workflow activities as described in D1.4: "APPENDIXES 4 - Description of the mounting of the timber frame elements and the procedure to guarantee the quality" (adjusted to the modular character of these buildings).

The focus of validation is: INSITER toolset checklists/documents for self-instruction, (theoretical) implementation INSITER toolset BIM-based self-instruction (Ref. D4.4).

Use Case 1:					INSITER INTUITIVE SELF-INSPECTION TECHNIQUES
Comparison of the IKEA-like self-instruction manual with the actual situation on site					
Relevant Demonstrator		Sustainer Homes			
Responsible Insiter Parter		DMO			
	description	**responsible partner**	**additional input**	**timeschedule**	**tools to be used in site testing**
Action 1	design & production of modules (incl. IKEA-like manual)	Sustainer Homes, producer	n.a	completed (description D5.3)	n.a.
Action 2	create BIM Model & prep.for on- site use	RDF (continues SBR's duties)	DMO	in time	IFC view er
Action 3	upload BIM to server	RDF	n.a	in time	n.a.
Action 4	follow the w ork-flow /on-site observations/comparison s	DMO, Sustainer Homes	assemblers, project managers	completed (if required more visits)	INSITER methodology (D1.4 - APPENDIX 4)
Action 5	upload all relevant information to server	DMO	INSITER partners	in time	INSITER guidelines
Action 6	deployment of BIM model & instruction guidelines on INSITER softw are tools	assemblers, project managers	n.a.	n.a.	tablet, mobile app
Action 7	checks & reports	assemblers, project managers	n.a.	n.a.	INSITER softw are tool
Action 8	field demonstration	DMO	INSITER partners, Sustainer Homes	INSITER partners, Sustainer Homes	INSITER mobile app. (D4.4) + other tools

Table13: data sheet use case 1

Explanation

- Without INSITER solution: IKEA-like manual (ref.D5.3)

A (paper) mounting instruction (IKEA-like manual) was available for the installers. Our aim within this use case is to compare this manual with the actual situation on site. Based on that, we identify how the BIM-model can be used for self-instruction within the scope of a digital VR instruction: facilitating assembly on site.

- With INSITER solution: D4.4

A mobile app is suggested as the main suitable INSITER software solution with respect to a dynamic instruction-based tool targeting the assemblers. Software able to create self-instruction content that can be viewed on any mobile device is under development, based on the BIM model of the Office Lab, by RDF. For that, the initial BIM model is broken down into building parts, representing components with different properties, so that allocation of characteristics can be given to selected parts of the building. In addition, the sequence of a process can be adjusted to replicate selected building construction procedures. The modular character of this demonstrator makes it suitable for such purpose.

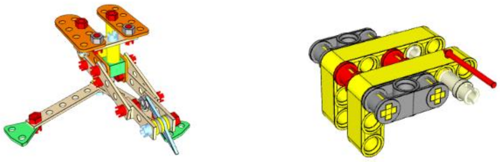


Figure 31: *Screenshots of the literature reference examples that RDF uses for the developments in D4.4.*

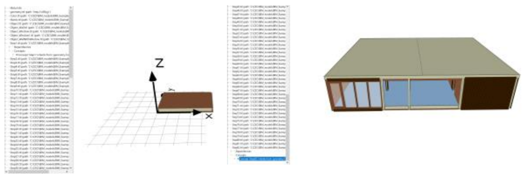


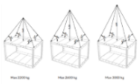
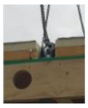
Figure 32: *Screenshots of the developments in D4.4 using as a reference the available BIM model of the Delft case*

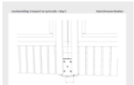
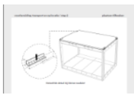
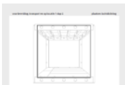
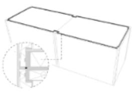
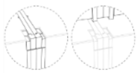
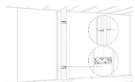
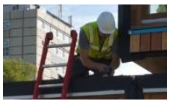
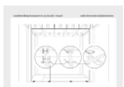
The advancement of the INSITER solution: By using the INSITER solution the previous paper instructions is given by means of software. Software can: 1. guide you through the process; 2. support mounting related virtual instruction.

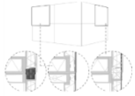
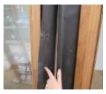
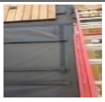
The findings of the on-site activities are presented in Table 14: validation Case study 1 Sustainer Homes including selectively actual photos, while we give advice for a potential improvement of the instruction. This suggestion gives the framework for self-instruction within STEP 7 of INSITER methodology, with respect to the demands of these modular structures. Examples from both the Office Lab & the Living Lab have been used for this table, incorporating into each activity some on site experience.

Validation

STEP 7 INSITER methodology (reference workflow: D1.4 - appendixes 4)	**IKEA-like manual** (without INSITER)	**Real on-site situation**	**Proposed instruction** (framework for checklist/self-instruction documents material)
Activity 1 Transportation to the building site & preparation	n.a.	• A toolbox meeting for safety and mounting instructions was done 	• Protect the modules against fragility; • Safety instructions: attendance list; • Mounting instructions: documents needed at building site; workflow: points of focus

Activity 2 Unload, storage and transport of the elements on site		• The modules were provisionally uploaded and then were hoisted and placed on the exact position. 	• Checking the elements: 1.right elements; 2.right condition: no visible damages; water resistant layers in good order; insulation in good order; elements in accordance with design • Where to store the elements temporary? • How to place the wooden blocks?
Activity 3 Protection of elements	n.a.	• The mounting materials were delivered inside one of the modules. 	• How to protect the elements against weather influences? • Where to store the mounting material?
Activity 4 Hoist and hoist provisions			• Where to place modules? • How to access building materials such as tape and insulation? • How to hoist the elements?

Activity 5 Placing the elements (incl. anchoring & fixing plan)	  	• checking the foundation  • preparing the elements for placing   • placing the elements on the steel corners  • fixing the elements for placing 	• Is the foundation in the right place and the right height? • Add insulation material in the floor; • Release all (water resistant) layers which are fixed for transportation without damaging the foil; • Place hoist corners according to drawing detail; • Take care that the water resistant layers are in the right place; • Place Panelseal on the columns close to the inside; • Instructions on how to place the seal.
	  	• fixing elements to each other      	• Remove hoisting facilities; • Place the next element and use a glue clamp for the first fixation; • Check that the water resistant foil is well positioned; • Connect the two elements with a connection plates.
		 	• Check visually for gaps and a good connection of the insulation; • Screw the floors of the modules together. Use a glue clamp.
		• Roof-work   	• The insulation of the roof is partly removed for hoisting and has to be repaired afterwards; • Place insulation in hoisting holes and fill holes with PUR; • Repair the water resistant layer; • Check for a good slope.

Activity 6 Sealants, water resistant layers & overlap of foils		 	• How do I treat edges, connections, seams, discontinuities?
Activity 7 Adjustments & repair works	n.a.	 	• Stick, glue, tape.
Activity 8 Treatments to the elements (with respect to air-tightness)		       	• Tape fixing plates; • Tape the joints between elements (one line from ceiling, walls and floor); • Repair holes above column with wooden block and tape it airtight; • Place wooden inlay in the floor and tape it airtight; • Make lead-through for cables airtight; • Place wooden rounds and make it airtight for under / over pressure; • Make an airtight lead-through for ducts and cables.

• Improves information based on tailor made instructions and preventing most common errors • Improves feedback on realized quality • Helps to create as-built model • Increases accuracy; easy access/view of details based on BIM; • Helps to create awareness for building quality	• Involvement and commitment of all chain partners is needed to use the Insiter-methodology • Requires an up-to-date BIM-model (with last minute changes) • The use of delicate mobile devices (ipads, phones) is not handy with heavy mounting work and needs internet connection

Table 14: validation Case study 1 Sustainer Homes

3.2.2 Use Case 2: Identify right moments for visual inspection and inspection with equipment

The context: The main focus of this use case refers to the detection of the right moments for visual inspection and inspection with equipment with respect to the assurance of airtightness during construction. Here we discuss the implementation of self-inspection within step 2 (checking of ordered components) and step 7 (self-inspection during construction) of the INSITER methodology following the proposed analytical methods of building components of D1.4 and the overview of INSITER measurement tools to be applied on a theoretical basis from D5.1 and D5.2.

The focus of validation is: INSITER toolset checklists/documents for self-inspection with respect to air tightness, (theoretical) implementation of INSITER toolset for measurement with respect to air tightness.

Use Case 2:					
Identify right moments for visual inspection and inspection with equipment					
Relevant Demonstrator		Sustainer Homes			
Responsible Insiter Parter		DMO			
	description	**responsible partner**	**additional input**	**timeschedule**	**tools to be used in site testing**
Action 1	create BIM Model based on 2D drawings	RDF (continues SBR's duties)	DMO, Sustainer Homes	completed	IFC viewer
Action 2	break down the BIM model into components	RDF	DMO	D4.4 M36 in time	IFC viewer
Action 3	upload BIM & relevant info to server	RDF, DMO	INSITER Partners, Sustainer Homes	in time	n.a.
Action 4	load BIM components on the tablet for visual on-site comparisons for selected elements	n.a.	DEMO, Sustainer Homes	monitor the possibility of following another project from Sustainer Homes	tablet, mobile phones
Action 5	follow the work in progress & perform visual inspection	assemblers, inspectors	DMO	Completed (if required, more visits)	INSITER methodology
Action 6	check the airtightness of the joints performing measuring	(UNIVPM) to be discussed and decided; this activity is proposed in principle	DMO	Monitor the posibility of following anothr project of Sustainer Homes	Air leakage test
Action 7	insert & store the measurement values	assemblers	DMO	as above	INSITER toolset
Action 8	check & approve the values	inspectors	DMO	as above	INSITER software tool
Action 9	upload all relevant information to server	DMO	INSITER partners	in time	INSITER guidelines
Action 10	report quality; decision making	inspectors	DMO	n.a.	INSITER software tool

Table15: data sheet use case 2

The analytical methods of building components of D1.4 (see Table 2: Critical and recurring inefficiencies) gave the framework for what we were looking for from our visual inspections on-site. Although it should be pointed out that Delft demonstrator is a modular structure: having a unique character within the validation of INSITER methodology on-site.

The proposed checklist for self-inspection for this visual inspection according to the detection of the right moments within the construction process can be derived from D1.4 Appendix 4. Seeking to validate this checklist during our on-site activities, reference material was collected to confirm these descriptions through real on-site examples.

No measuring with special equipment has been performed. Such testing possibilities are to be discussed within the consortium together with the overall planning of the measurement campaigns within INSITER, while monitoring the potential with Sustainer Homes to follow another project in order to perform such activities. Such potential is discussed below on a theoretical basis, integrated into the right moments within the INSITER methodology. Due to the replicable character of this building process, no new descriptions will be needed for such a potential as these two buildings are already presented examples from Sustainer Homes. On the other hand, as long as the proposed measuring technologies below will be tested within other demonstrators for comparable use cases and its performance on-site is validated, maybe an alternative approach can be discussed instead of following another project.

Validation

Critical moments (related to on-site activities)	**Real on-site situation**	**INSITER checklist for visual inspection** (given as examples from most frequent observed errors)	**INSITER toolsets solution** (self-inspection theoretical content & proposed testing)
1. After transport (STEP 2 of INSITER methodology)	Some damages on the foil while removing temporary fixation from transportation. For the Living Lab, workers taped the water-resistant foil layer with airtight tape to secure the overlapping of the seams between the modules. A good practice example, also as an intervention: recovering potential energy performance shortcomings from transport-related damages. 	• Did the temporary fixation damage the water resistant layer after it was removed? • Are there damages causing problems when applying airtight sealing? • Did I receive the right material/ products for making the joints and the lead-through airtight?	The inspector shall check, record and report on the tablet/mobile potential damages following the methodological framework of the INSITER software tool during uploading on-site. • Use QR code scanner to check the right material and report the quality of the arrived components and materials (refer to Cologne demonstrator Use case 1.1). • A checklist for self-inspection could be displayed on INSITER toolsets. • A list of materials (e.g. foam-tape, tape, PUR, sealing rings for ducts, cables, pipes etc.) could be displayed on INSITER toolsets.
2. Preparation for installing (STEP 7 of INSITER methodology)	Instruction from the IKEA-like manual was given on how to put/check on-site 1 line of semi-closed structural Celdex panelseal on-site.  	• Is the Panelseal (foam-tape) applied in the right way at the right place? • Is the water resistant layer placed in such a position that it is in the right position after placement?	• A checklist for self-inspection could be displayed on INSITER toolsets. • A list of materials and equipment/tools needed for the following activities could be displayed on the INSITER toolsets.
3. After placement (STEP 7 of INSITER methodology)	   Note: These photos were taken before taping; after, all these overlaps were properly closed  	• Are the elements connected in such a way that no gaps are visible? • Are the joints connecting according to the details? • Is an overlap of the water resistant layer of xx cm possible?	• A checklist for self-inspection could be displayed on INSITER toolsets. • Self-inspection content for critical details based on the BIM model could be given. The installers could check, compare and record the conditions (ref D4.4). • Dimensional checks on the overlapping of the sealing could be facilitated and the results could be recorded on the INSITER toolsets (e.g. make a note on the BIM model using the D4.4 on the relevant detail).

<table>
<tr>
<td>4. Finishing (before closing the structure)

(STEP 7 of INSITER methodology)</td>
<td></td>
<td>

Are all the needed joints taped from the inside?
Is the taping done in the right way?
Are all lead-through of ducts, pipes and cables made airtight is the right way with the right material.

</td>
<td>
<u>INSITER toolsets for measurement</u> (on a module level)

perform Ultrasound leakage test as described in D1.5;
extract the ultrasonic level map for the selected walls of the module. Reference e.g. from the lab test mock-up of D5.2:

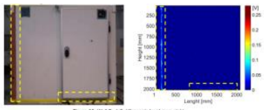


Figure 23: Wall B , left; Ultrasonic level map, right.

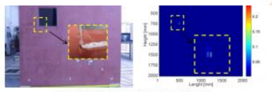



Figure 22: DRAGADOS panel (Wall A), left; Ultrasonic level map, right.

record & process the values of spatial leak detection in INSITER software,(comparison with KPIs-based equivalent ones).
approval or not to continue the workflow.

Store the values & incorporate them later into the BIM model to develop the as-built situation (treat the ultrasonic level map as layers on walls on REVIT).

explanation: As we seek to measure leakages from the joints, an ultrasound wave detection range testing method is required. The proposed available testing for such case within the INSITER consortium is the Ultrasound <u>air leakage test </u>described in D5.2. as performed on DRAGADOS-UNIVPM mock-up.
<table>
<tr><td>3D Air leakage test</td><td>EN ISO 9972 - Blower door test</td><td>Ultrasonic waves detection</td><td>Spatial leak detection in the order of 3-20 mm</td><td>About one hour for an area of 200 cm x 200 cm</td><td>3000 euro

Similar to Blower door equipm ent</td><td>The ultrasonic probe is manually moved and its position tracked by automatic positioning system as the SoundBrush one</td></tr>
</table>
To be discussed with UNIVPM if can be performed in the closed structures replacing blower door test.
</td>
</tr>
</table>

• Tailor-made systematic solution for quality assurance; • Expect improvement of energy performance and quality due to multiple checks and tests; • Dynamic functionalities reduce negligence and increase quality conscious behavior; • Facilitates multi-levels of inspection based on different expertise and level of responsibility.	• Testing with tools requires expertise for performing the test and evaluate the results; • Testing with tools take additional time during mounting (but saves time and money in the end • The use of delicate mobile devices (iPads, phones) is not handy with heavy mounting work and needs internet connection

Table 16: validation Case Study 2 Sustainer Homes

3.2.3 Use Case 3: Compare the as-designed situation with the as-produced and as-built situation

The context: This use case brings together the previous 2 use cases by summarizing them in the overall 8-step INSITER methodology. Here we discuss also preliminary findings based on observations by comparing the as-designed with the as-built situation. The originally BIM model designed from the available 2D drawings represents the as-designed version. With the QR codes and the proposed checklists during delivery, we record the potential gaps in quality according to what arrives at the construction site and in what condition, as a representative point of the as-delivered situation. The records of the previous 2 use cases will form the updates required to extract the set-ups for adjusting the BIM model elements based on the as-built situation during construction.

Use Case 3:					
compare as-designed situation with as-delivered and as-built situation					
Relevant Demonstrator	Sustainer Homes				
Responsible Insiter Parter	DMO				
	description	**responsible partner**	**additional input**	**timeschedule**	**tools to be used in site testing**
Action 1	design & production of modules	Sustainer Homes, producer	n.a	completed (description D5.3)	n.a.
Action 2	create BIM Model & break it into components	RDF (continues SBR's duties)	DMO	in time	IFC view er
Action 3	prepare BIM for on-site use and upload it to server	RDF	n.a	in time	n.a.
Action 4	upload all relevant information to server	DMO, Sustainer Homes	assembler, construction w orkers	in time	INSITER guidelines
Action 5	transportation of modules on site	producer	transport company	monitor the possibility of follow ing another project from Sustainer Homes	n.a.
Action 6	start on-site w ork flow w ith scan of QR codes during uploading	assembler, construction manager	DEMO, Sustainer Homes	as above	QR scanner
Action 7	check and report quality	assembler, construction manager	DMO	as above	INSITER softw are tool
Action 8	deployment of BIM models for on-site use	assembler	INSITER partners	as above	Tablet, mobile app INSITER softw are tool
Action 9	check the airtightness of the joints performing measuring	(UNIVPM) to be discussed and decided, this activity is proposed in principle	DMO	monitor the possibility of follow ing another project of Sustainer Homes	Air leakage test
Action 10	update the BIM model/components according to the checks and reports of the previous 2 use cases	n.a.	n.a.	n.a.	n.a.
Action 11	generation of list of adjusted objects based on comparisons	n.a.	n.a.	n.a.	n.a.

Table 17: validation Case Study 2 Sustainer Homes

Explanation

The combination of the previous 2 use cases gives the possibility to compare the as-designed with the as-built situation. That is the reason that this 3rd use case is considered as an overall one through which the 8-step INSITER methodology is presented. Having this as a reference, we discuss a preliminary building performance validation. Here we discuss the implementation of STEP 8 of the INSITER methodology. These records correspond to the selected tools and procedures to be applied within this demonstrator.

INSITER 8-Step Methodology	Application for the Sustainer Homes demonstrator (theoretical methodology to compare as-designed with the as-built)
STEP 1 mapping	• Identify the correct working area and the area to store the modules • Check the actual on-site conditions • Check the correctness of the founding structure
STEP 2 checking of ordered components	• Check the received wooden modules; - scan the QR codes or another identification mark on the modules during delivery for controlling the right element - check the received module for damages and other short comings • Check all other materials (insulation, foils, flashing, sealants, connection material) for the right quality and quantity. • Report quality and received material using the INSITER software;
STEP 3 BIM for on-site construction	• update the BIM model for on-site use; - The BIM model to be used as a basis for virtual instruction is updated incorporating available 2D and 3D drawings and GIS data; - The BIM model is compatible with the databases of the involved stakeholders; - The BIM model is in a compatible format for the IFC viewer to be opened in the mobile app; - The instruction content is updated and compatible with the INSITER software tools;
STEP 4 BIM-based AR	• With the focus on airtightness we decided not to apply AR to support the self-instruction. For a relative simple task (apply foam tape to the modules) a 2D-drawing is sufficient.
STEP 5 clash detection	n.a.
STEP 6 self-instruction	• Update the BIM model for on-site use based on actual conditions on site; -Schedules and planning related data are included in the BIM model; -Expected weather data are included; -Self-instruction content is updated accordingly (e.g. how to protect glass wool insulation material against rain, how to hoist and mount the modules if it is windy)
STEP 7 self-inspection	• Use mobile app (ref. D4.4) as an INSITER tool facilitating self-instruction content for mounting; - Focus on detected criticalities (e.g. airtightness, replacement of insulation material on the hoisting corners, mounting of the second floor with respect to the connection needs of the piping details of the corners) • Evaluate and record inconsistencies; • Check and report quality using the INSITER software; • Perform air leakage test; • Record & process the spatial leak maps on BIM; • Import measurement data on the INSITER software tool and compare with KPIs values;
STEP 8	• Updating BIM towards as-built situation (containing set-up information) - Check the preliminary performance of the building according to the as-built situation

Table 18: INSITER 8-step methodology

Validation: preliminary findings

Two examples of the on-site experience are described below, showing the consequences for quality assurance (self-instruction, self-inspection) in relation to the potential use of a BIM-model.

- Example 1

For hoisting the modules, the instruction that was given in the IKEA-like manual was to remove a piece of insulation from the modules' corners, save it, place the hoisting and replace the insulation later. No specific instruction was given on how exactly to do that. The BIM-model was based on the 2D-drawings and corresponds with the IKEA-like manual. In fact the hoisting company advised to use a different kind of hoisting equipment and the modules were changed in the factory. The BIM-model was not adjusted anymore to the new situation.

The use of an updated BIM model at this point could have given useful self-instruction and self-inspection content by:
1. facilitating detailed instruction on how to deal with this work;
2. feedback of the actual amount of insulation material used during the replacement: info that could be processed later for the as-built situation.

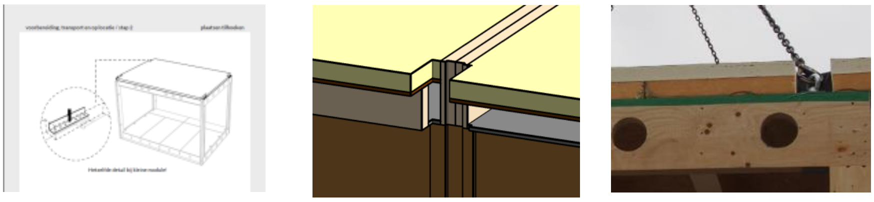


Figure 33: BIM model checking (Ikea-instruction, BIM-model and actual situation)

Expected theoretical impact on building performance:

When the opening in the insulation layer for hoisting facilities is not good repaired, cold bridges might occur. When the airtight layer is damaged, the airtightness of the building is not guaranteed anymore. The percentage of total heat loss depends on the whole building R-value and the whole building air exchange rate during normal operation and it is not directly equal to the measurement values during performing 3D air leakage test or a thermal scan.

Expected improvement with the INSITER solution:

With the INSITER solution, the extracted ultrasonic level map shows possible air leakages during the assembly period. This gives the assembly workers the possibility to repair the unwanted openings in the construction. Repair of those unwanted openings after the building is ready, will be more difficult or even impossible and will cost more time and money.
The same principle applies for the thermal insulation. Through the INSITER solution we first take care of awareness, self-instruction and self-inspection of the insulation layer. Insufficient quality of the repaired insulation layer at the hoisting facilities will not pass the test and have to be repaired in a better way. In the theoretical case that insufficient quality was delivered and not noticed, a final thermal scan might detect the problem area.
As the preliminary performance of the building during design has been calculated considering the amount of insulation material that should be there as a unified layer (not taking into account the inconsistencies made due to the construction needs for hoisting: regarding cutting and replacing an amount of it in the hoisting openings), the initial calculated

performance of the building is not accurate. A decision has to be made to repair or recalculate the expected performance of the buildings by redefining the overall R-value or Air exchange rate of the building based on the as-built situation. The BIM-model has to be updated based on the as-built situation.

- Example 2

The modules of Sustainer Homes are using a double layer of airtightness seals. One seal between the modules (foamseal) and one layer at the inside of the Modules after placing (tape).

Regarding the use of the second layer of seals (tape) of the joints of the modules, the given instruction was to:

1. tape the joints between elements (one line from ceiling, walls and floor);
2. tape fixing plates.

The BIM model can be used as a reference for self-instruction and self-inspection:

Self-instruction

- visualising the areas that need to be taped at the joints of the modules, with the right material and the way it has to be done (see figure 34);
- visualising the corner details, with the right material and the way it has to be done;
- visualising the fixing plates that need to be taped.

No deviation is allowed. So all the joints, fixing plates and corners has to be taped, to guarantee the airtightness. Missing tape or wrong applied tape has to be replaced.

Self-inspection:

Visual inspection of the work (is the right tape present and used in the right way) is the evidence of good and sound work and shown by pictures in the as-built building dossier.

Figure 34: BIM model checking

Expected theoretical impact on building performance:

Taping can prevent air-leakages securing air-tightness. No deviations from the preliminary expected contribution towards airtightness are expected here, as the construction workers taped all the indicated internal areas properly.

Expected improvement with the INSITER solution:

The main expected improvement of the INSITER-methodology is the raised awareness of the importance of airtight building, the self-instruction (right material used on the right place in the right way) and the self-inspection of the delivered work. The methodology is structuring the process for 100% right work.

TESTINGS OVERVIEW SUSTAINER HOMES, DELFT

Use case	M36 Nov 17	M37 Dec 17	M38 Jan 18	M39 Feb 18	M40 Mar 18	M41 Apr 18	M42 May 18	M43 Jun 18	M44 Jul 18	M45 Aug 18	M46 Sept 18	M46 Oct 18
Use case 1: Comparison of the Ikea-like self-instruction manual with the actual situation on site	On-site observations are completed											
Use case 2: Identify right moments for visual inspection and inspection with equipment								On-site 3D-air leakage testing to replace blower-door (to be discussed with UNIVEPM)				Reports
Use case 3: Compare the as designed situation with the as produced and as built situation	On-site observations are completed											

Table 19: Overview testing activities

3.3 Real measurement values / demonstration results from each use case

Introduction and objectives

Purpose of the demonstration and target group

The main goal of this demonstration case was testing the INSITER methodology and tools in a virtual way on a real project. At the time of the start of this project the INSITER methodology was developed, but the tools were not ready yet. This test case gave the INSITER team a good opportunity to see whether the 8-step methodology was working or not and how to integrate the tools. With quality assurance as the most important factor we focussed on the use of the Ikea like self-instruction. Although the Ikea-like self-instruction was on paper and not integrated in the BIM-model, it taught us how the self-instruction was used and what level of detail was needed.

Observations during the mounting process of the prefabricated elements taught us when self-inspection (visual and with equipment) was the most appropriate and what should be taken into account. The ultrasound measurements to control the airtightness of the connections and cable and duct entries followed the developed procedure in D1.5.

A BIM-model was generated from the 2D (as designed) drawings with the purpose to learn how it could support the INSITER methodology. The demonstration and evaluation were done in close contact with the designer/ developer of the modules, the mounting crew / contractor and the building owner.

Goals and objectives associated of the demonstration

The main objectives of this demonstration case were for Sustainer Homes as designer/ developer of the modules:

- quality assurance (with a focus on airtightness of the building envelope);

- improvement of the design and production based on the findings during the mounting phase.

This follows Figure 35 as mentioned in D1.1.

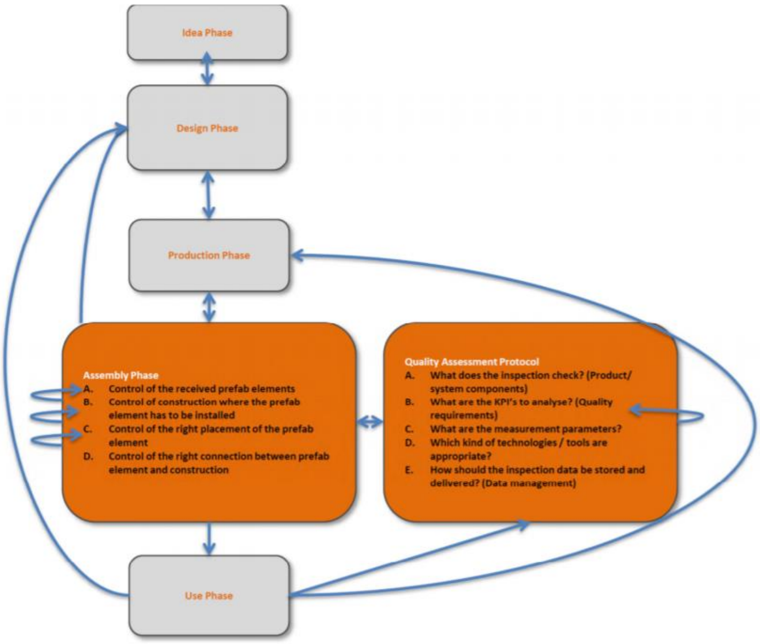


Figure 35: INSITER protocol focus on the on-site assembly phase

For the mounting crew/ contractor:

- Learning from their first experience to mount the Sustainer Homes modules;
- Delivering the right quality.

For the INSITER project:

- to test the INSITER 8 step methodology and tools in a virtual way. The tools were not ready at the time the demonstration project was built;
- to test the procedure for ultrasound measurements and how to deal with the results.

The focus was on:

- Checking of ordered components (step 2);
- Creating a BIM model (step 3);
- Self-instruction (step 6);
- Self-inspection (step 7).

Contribution of partners

- Responsible demonstration work package leader: 3L
- Responsible INSITER partner for Sustainer Homes demonstration: Demo (in the beginning SBR)
- Responsible BIM-modelling: RDF
- Responsible use of inspection tool airtightness: UNIVPM.
- The ultrasound airtightness measurement itself was conducted by a Dutch adviser Gevelscan.
- The results were shared with all partners to improve the methodology and tools.

Description of the demonstration building

The demonstration case of Sustainer Homes in Delft was the first demonstration case for the INSITER methodology and tools. The Delft demonstration case consists of two types of buildings, an office building of 16 modular elements (four elements by four elements and one floor) built in May 2017 and student housing of four modular elements (one element by two elements and two floors) built in July 2017. The elements were prefabricated and mounted on site. The installation was installed on site after the modules were placed.

Figure 36: Office Building (1) and Student Housing (2) situation August 2018

Sustainer Homes is a young Dutch supplier of prefabricated houses and offices based on innovative wooden modules. Sustainer Homes takes care of the design, fabrication of the modules and mounting on site.

Figure 37: Placing modular elements

The main goals were to evaluate the use of the INSITER methodology and quality assurance of the building phase.

Performance of the building envelope

The insulation and airtightness values for the building envelope of the office lab of Green Village are quite good:

- Windows with triple glazing (U-value 0,7 W/(m²·K). The frame is made of a modified wood.
- Walls with 220mm glass wool insulation with a lambda value of 0,035 W/ (m¹·K)
- Roof with PIR insulation (between 130mm and 220mm because of the slope)
- Floor with 310mm glass wool insulation with a lambda value of 0,035 W/ (m¹·K)

This gives an estimated calculated R_c-value for the floor of 7.0 (m²·K)/W, for the wall of 4.0 (m²·K)/W and for the roof of 5.9 (m²·K)/W.

For the airtightness of the building envelope a specific value is not mentioned. The airtightness has to be good according to the program of demands. This might refer to Class 2 Good as mentioned in the SBR-Publication “ Luchtdicht bouwen” (Airtight building). The corresponding value for this is a $q_{v;10}$ between 0,3 and 0,6 $dm^3/s.m^2$.

Performance of the installation

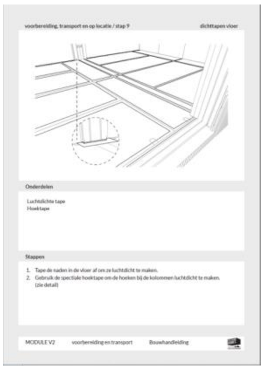
For heating a heat pump (air- water) is used. Heat is collected in a barrel of 50 litres. The warm water is used to condition the air for the hot air heating. A heat exchanger is used for energy efficiency ventilation.

In this project a number of devices / installations are running on DC (direct current) during a test period (led lighting, infrared zone heating, laptops and mobile telephones). The DC supply is coming from a combination of solar panels, battery storage and DC/DC converters. The installation is now operational, a part of the office uses DC coming from the solar panels, a battery and in case of shortages from the AC network. The needed amount of solar panels and the capacity of the batteries is under investigation and will differ from office to office. The test results are not available at the moment.

Description of set of demonstrations

The demonstrations for the Delft case had a focus on three use cases:

1. The use of self-instruction material by comparison of the IKEA-like self-instruction manual with actual situation on site. The IKEA-like self-instruction was developed by Sustainer Homes. Evaluating of the use of the self-instruction material by the craftsmen on site gave a good input how self-instruction material should be used, the kind of information and the level of detail needed. This use case is described in detail in D5.4 and no further testing activities has been performed.



Ikea-like self-instruction

2. Identify right moments for visual inspection and inspection with tools with a focus on the airtightness of the building envelope. The wooden modules were placed together on site. For the quality assurance was a focus on airtightness. All the steps needed to guarantee the airtightness were monitored and described. Ultrasound measurements were performed to check the realized airtightness quality of the connections.
3. Evaluate the proposed INSITER methodology and compare the as-designed situation, with the as-delivered and the as-built. A BIM-model was made by the INSITER team based on the 2D-drawings (as designed) of Sustainer Homes. Due to changes in the ventilation system, the hoist facilities and unfinished delivery of the elements, there was a difference between the as designed and the as delivered elements. The elements were finished on site which reduced the difference between as designed and as built. The change in design caused by changes in ventilation systems resulted in ad-hoc solutions on site.

3.3.1 Use case 2: Identify right moments for visual inspection and inspection with tools

Connection with other work packages

Due to the fact that the Delft demonstration case was the first demonstration case in the development stage of the INSITER tools the information gathered from the project was used for further development of the toolset.
The demonstration case of Sustainer Homes is generic described in D5.3 and the input derived from this project to improve the 8-step INSITER methodology in D5.4. The use of the BIM-model is explained in D4.4.
The airtightness of the Sustainer Homes building is tested according to the ultrasound measurement procedure as described in D1.5.

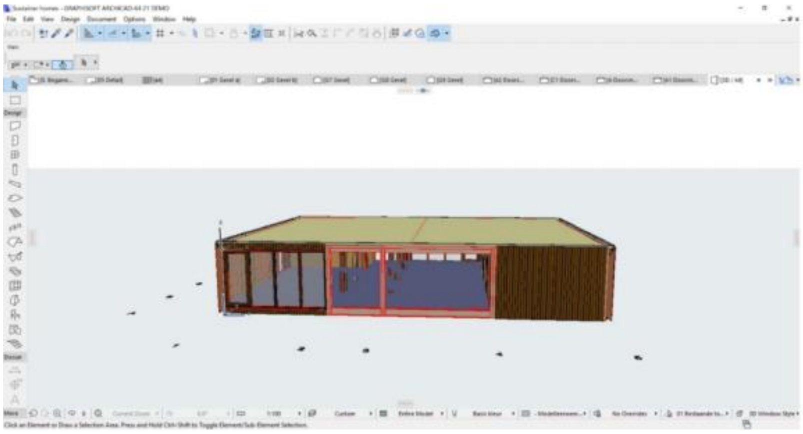
Development of BIM-model (step 3 of the INISTER Methodology and action 1 to 3 in use case 2)

The principle of the INSITER project is that the BIM-model is the bearer of all information. The model created for the Delft demonstration case shows a clear self-instruction model based on BIM / IFC data.

Use Case 5.2					
Identify right moments for visual inspection and inspection with equipment					
Relevant Demonstrator		Sustainer Homes			
Responsible Insiter Parter		DMO			
	Description	**responsible partner**	**additional input**	**timeschedule**	**tools to be used in site testing**
Action 1	Create BIM Model based on 2D drawings	RDF	DMO, Sustainer Homes	completed	IFC viewer
Action 2	Break down the BIM model into components	RDF	DMO	completed	IFC viewer
Action 3	Upload BIM and relevant info to server	RDF, DMO	INSITER partners, Sustainer Homes	completed	n.a.
Action 4	Load BIM components on the tablet for visuall on-site comparison for selected elements	DMO	DMO, Sustainer Homes		tablet, mobile phone
Action 5	Follow the work in progress and perform visual inspection	Contractor	DMO, Sustainer Homes	completed	tablet, mobile phone, camera
Action 6	Check the airtightness of the joints performing measurements	DMO	UNIVPM, Dutch adviser Gevelscan	completed	Insiter methodology - Ultrasound measurement (D1.4 App 4)
Action 7	Insert and store the measurement values	DMO	UNIVPM, Dutch adviser Gevelscan	completed	Insiter methodology (D1.4 App 4)
Action 8	Check and approve the values	DMO	UNIVPM, Dutch adviser Gevelscan, Sustainer Homes	completed	n.a.
Action 9	Upload all relevant information to server	DMO	n.a.	completed	n.a.
Action 10	Report quality: decision making	DMO	Insiter partners	complete	INSITER software

Table 20: Use case 2 Identify right moments for visual inspection and inspection with equipment

The 2D-drawings from Sustainer Homes were transformed to the BIM-model for the Office-project. The BIM-model is broken down into building parts, representing components with different properties, so that allocation of characteristics can be given to selected parts of the building. The modular character of this demonstrator makes it suitable for such purpose.



BIM model of Sustainer Homes Office

The Delft demonstration project had a focus on the use of self-instruction and self-inspection regarding the airtightness of the building envelope. The airtightness of the building envelope is an important factor in the total building quality and should be considered in all phases of the building process. We concentrate during the demonstration case on the self-inspection and self-instruction of the workers and how the 8 step INSITER methodology and tools can support them.

Checking of ordered components (step 2 of the INSITER Methodology and action 5 in use case 2)

The 16 modules were delivered on site and stored on “stelcon” plates. The additional material to mount the modules (coupling plates, screws, airtightness sealants and tape etc.) were packed in the modules.

- The storage place was fit for the temporary storage of the modules.
- A good entrance control of the received additional materials for mounting the modules was missing.

Figure 38: Delivery and storage of the modules

- Work that had to be done in the factory was transferred to the building site because of time reasons. The mounting had to start before all the elements were ready. The decision was made to transport the elements already to the building site and finish the elements there. So all the elements were there, undamaged but some unfinished.A checklist based on information given in Appendix 4 of D1.4 can be a good guidance. A checklist can be helpful to guide the worker through the important points. Did I receive the right material in the right condition, right quality and right quantity? Self-instruction (step 6 of the INSITER Methodology and action 5 in use case 2)

The instruction of the workers on site was done in two steps:

1. Toolbox meeting for airtightness. The toolbox meeting raised awareness on the importance of airtight buildings and information how to achieve the demands in the field of airtightness. INSITER will develop awareness training in the field of quality assurance D6.1.
2. Self-instruction by the Ikea-like manual. Although the Ikea-like self-instruction was on paper and not integrated in the BIM-model, it gave us input on the use of self-instruction material and the level of detail needed. The Ikea-like self-instruction can easily be adopted in the BIM system. The Ikea-like self- instruction was a step by step instruction without too many details. A good example of the procedure of mounting timber frame elements is given in Appendix 4 of D1.4. This information can be used to develop a broader self-instruction for quality and safety. Besides a broader self-instruction, the level of detail can be improved as well.

Self-inspection (step 7 of the INSITER Methodology and action 5 in use case 2 for visual inspection and action 6 for inspection with tools)

The demonstration project taught us that self-inspection takes place during several stages in the mounting process:

Visual inspection

In the Sustainer Homes case two layers of airtightness were applied. One layer of foam tape between the elements and one layer (adhesive tape) after the elements were connected. This results in three different steps for visual inspection:

The first step in visual self-inspection is the right application of the foam tapes for airtightness on the elements.

KPI: airtightness

- Threshold – foam tape applied according to the Ikea-like manual in the right way without interruption.
- Evidence: photos
- Action:

a. repair all differences between actual situation and the Ikea-like manual
b. upload the prove of the right position of the foam tape via the app-interface to the BIM-model

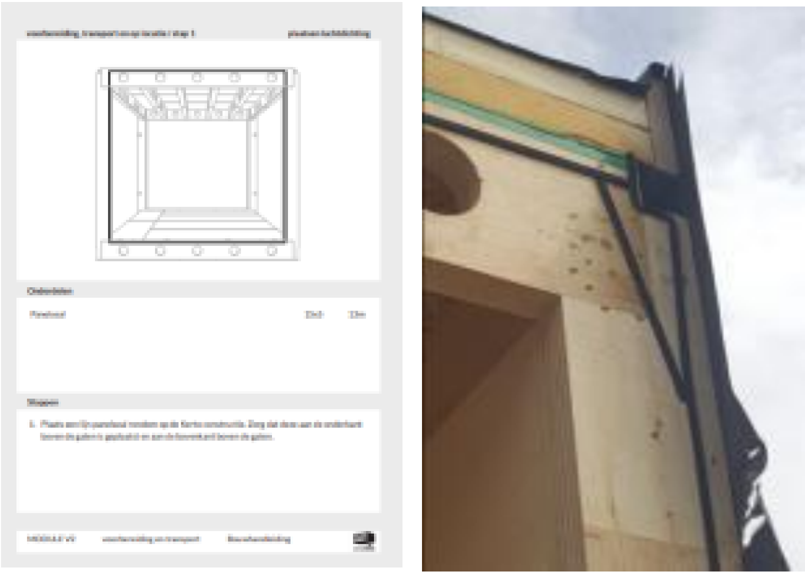


Figure 39: Example of Ikea-like manual versus actual situation

The second step in visual self-inspection is the inspection of the joints of the elements and the exits of cables, ducts etc. The foam tape is applied but does it work in the right way?

KPI: airtightness

- Threshold – no visual gaps are allowed between the elements and between the entry of pipes, ducts and cables through floor, ceiling and walls. Although we can calculate the allowed openings of the whole building depending on the size of the building and the airtightness demands, we don't accept any visuals openings.

Figure 40: Examples of situations where the elements are not 100% connected yet.

This was repaired during the mounting and fixation of the elements.

- Evidence: photos

- Action:

a. repair all visual gaps

b. upload the prove of the right application of the foam tape via the app-interface to the BIM-model

The third step in visual self-inspection is the right application of the adhesive tape.

KPI: airtightness

- Threshold – adhesive tape applied according to the Ikea-like manual in the right way without interruption.
- Evidence: photos

Figure 41: Adhesive tape instruction and application

- Action:

a. repair all differences between actual situation and manual

b. upload the prove of the right application of the adhesive tape via the app-interface to the BIM-model

Ultrasound measurements

The next step is ultrasound measurements. Not all openings are visible (cracks, labyrinth and other small openings). Ultrasound measurements detect openings which are not directly visible. The use of ultrasound in the building sector is relative new. It gives already an indication of the airtightness of the joints and lead-through before the whole building is closed. An experienced adviser / user is needed to measure in the right way and to interpret the results.

The ultrasound measurements can be made visible (as shown in D5.2). Colours in this case are RMS ultrasonic sound level in Volts. The procedure of the airtightness measurements is described in D1.5 & 5.4. The ultrasound measurements were focussed on the frequent errors as described in D1.1.

- Control of the tightness of the joints of building elements;
- Control of gaps around services.

The following equipment is used for the ultrasound measurement in Delft

- Sound level meter to measure the environmental noise inside and outside the building to determine where to place the receiver (the place with the lowest background noise level)

Figure 42: Sound level meter used in Delft

- Ultrasonic generator: Sonotec Sonaphone T Ultrasonic Transmitter Version 2.0 with a transmission frequency of approximately 40 kHz.

Figure 43: Ultrasonic generator

- Spherical Transmitter SONOSPHERE

Figure 44: Transmitter

We used two types of receivers during the testcase in Delft:

1. The Sonotec Sonaphone R is used for the first quick inspection to make the transmitted ultrasound audibel.
2. The Sonotec Detector Ultrasonic Receiver Sonotight is used together with an industrial camera, a laptop and Ultragraphix software to make the transmitted ultrasound visible.

- Ultrasonic receiver: Sonotec Sonaphone R

Figure 45: Ultrasonic receiver used for first quick inspection

- Ultrasonic receiver: Sonotec Sonotight

Figure 46: Ultrasonic receiver, camera and Ultragraphix software

KPI: airtightness

- Threshold - the ultrasound method indicates possible problems with the airtightness - but gives no exact information about the size of the opening.
  As mentioned in D1.5 §5.6, if the attenuation is higher than 20dB an airtightness leak can be assessed and localized. An adviser or expert user is able to analyse the results, eliminate measurement errors and give feedback.
- Evidence: ultra sound images with a clear scale of acoustic attenuation.
- Action:

a. evaluation of the results by adviser or expert user of ultrasound measurements. In case of exceeding the threshold, a decision has to be taken by project manager.

b. upload the digital photo of the ultrasound measurement connected to the Quid-code (scanned via a QR-code on the element) via the app-interface to the BIM-model.

Test setup Ultrasound measurement

The environmental noise was measured inside the office building and outside the office building. The environmental noise level in the office building was lower than outside. So, we decided to place the transmitter at the outside and the receiver inside.

We selected four places where frequent errors in airtightness occur:

1. Connection between modules (2 different places);
2. Window frame;
3. Cable entry through the floor;
4. Duct entry through the ceiling.

The spherical transmitter together with the Ultrasonic generator was placed at the outside near the places we want to investigate for airtightness.

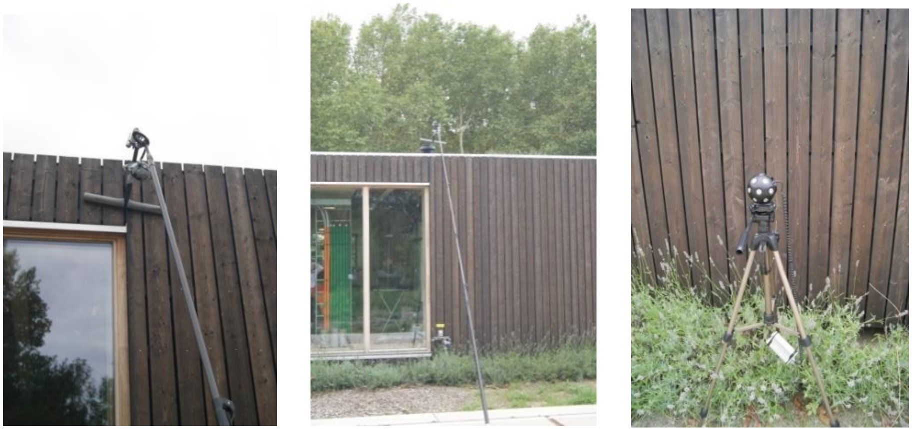


Figure 47: The transmitter and generator were placed near the places to be investigated for airtightness. For the cable entry through the floor the transmitter and generator were placed under the module.

We used two types of receivers:

1. For the first quick idea we used a receiver which makes the ultrasonic sound waves audible (ultrasonic).
2. For more detailed information we use a receiver together with a camera and laptop to make the ultrasonic sound waves visible (ultragraphic).

Figure 48: Test setup with receiver which makes the ultrasound audible (ultrasonic)

Figure 49: Test setup with ultrasonic receiver (2), camera (1) and laptop (3) (ultragraphic) which makes the ultrasound visible (ultragraphic)

Figure 50: Animation of the test setup (source Sonotec)

The transmitter (40.000 Hz) was put on a high level of transmission (120 dB). With the ultrasonic method we get a first impression of possible air leaks (Figure). With the ultragraphic method we are able to visualise the received ultrasound level for the tested area (Figure).

For the ultragraphic method the following procedure is used:

1. Identify the area to be tested;
2. Measure the environmental noise (inside and outside)
3. Place the receiver at the lowest side (inside or outside the building envelope) of the environmental noise;
4. Place the transmitter at the opposite side, in the right position and switch it on. Adjust the emission of the transmitter depending on the signal to noise ratio (has to be above 20dB at the reception side)
5. Start the Ultragraphyx-Software on the laptop;
6. Connect the camera with the laptop;
7. Place the camera in the right position and take a photo of the tested area;
8. Control the Bluetooth connection between receiver and laptop;
9. Start with scanning the tested area with the ultrasonic receiver. During the test the position of the ultrasonic receiver is seen on the computer by a red circle;
10. Stop the scanning and edit the image of the ultragraphic scan;
11. Evaluation of the results by an expert.

12. Upload the image (coupled via the QR-code of the element) in the BIM-system for further evaluation and evidence.
13. Evaluation of the results by project manager and take corrective measures if necessary and give feedback to the involved parties.

Figure 51: During measurement the receiver is seen by the camera and plotted on the photo with a red circle

Test results Ultrasound measurement: Airtightness of the joints of the modules

The ceiling plates were removed and the airtightness was visual checked. The green tape was ripped.

We first checked the airtightness of the connection with the ultrasonic method (to make the transmitted ultrasonic sound audible). No sound was received at the connection. So despite the ripped tape in one connection the connection is still airtight, due to the fact that a double layer of sealants is used (foam tape between the elements and adhesive tape under the elements).

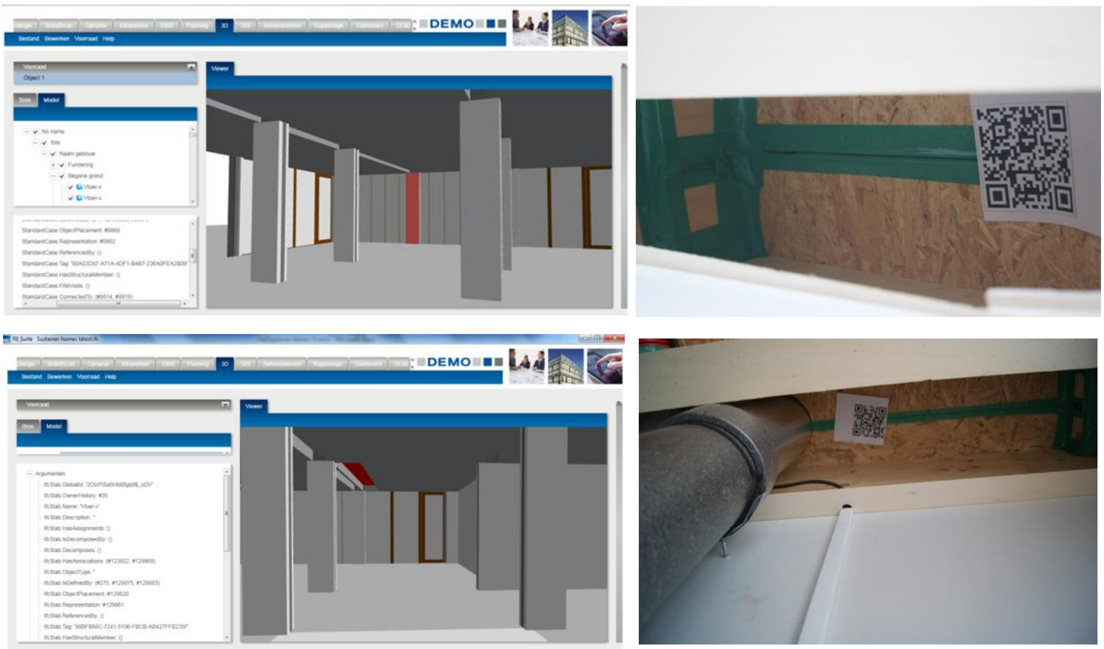


Figure 52: *Position in the BIM-model and visual inspection*

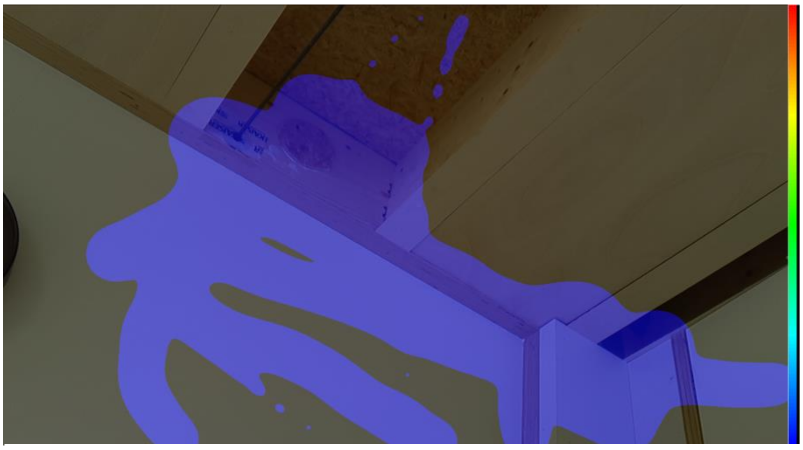


Figure 53: Ultragraphic image of the airtightness of the connection between the modules.
The image shows no ultrasound attenuation through the joints of the module.

The receiver is sensitive for knocking against hard surfaces. A distance spacer is not used because the scratching of the spacer influences the results. We rejected the result of this measurement because of measurement error.

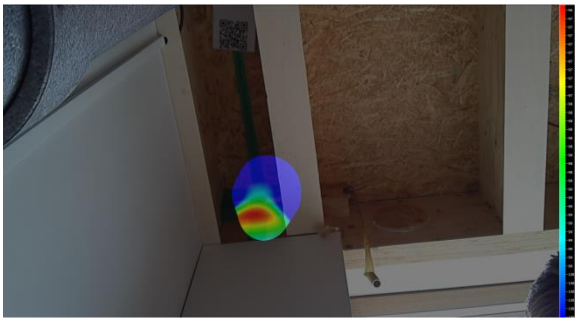


Figure 54: Misinformation of air leak caused by sensitivity of the receiver for knocking against hard surfaces

Airtightness of the window frame

During the measurements a leak was found near the window frame (Figure 56). The connection between the glass and the window frame was airtight. The ultrasound was measured between the window frame and the wall.

Further investigation taught us that during the construction the airtight sealant was applied. The connection between the wooden beam and the window frame is not 100% airtight. This connection was made in the factory and not influenced by the workers on site (Figure 57).

- Threshold: The difference in sound pressure level between the relative small hole in the left corner of the window frame (-86 dB illustrated as red in the image) and airtight places (-100dB illustrated as blue in the image) is below the threshold of 20dB.
- Action:
  - This air leak is relative small and does not demand re-work.
  - Feedback to the factory is needed to take appropriate measures to prevent such problems (although this one is relative small) in the future.

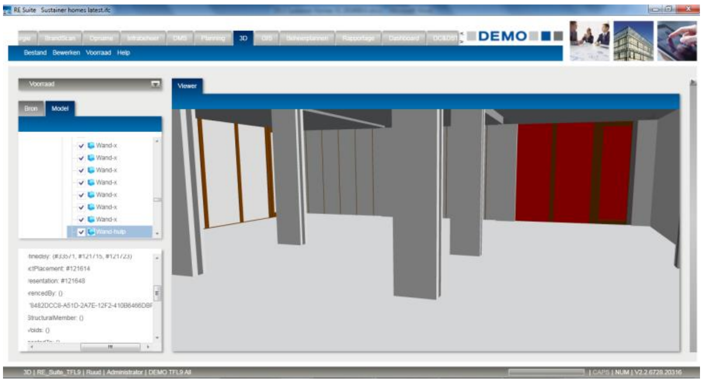


Figure 55: Position in the BIM-model and visual inspection

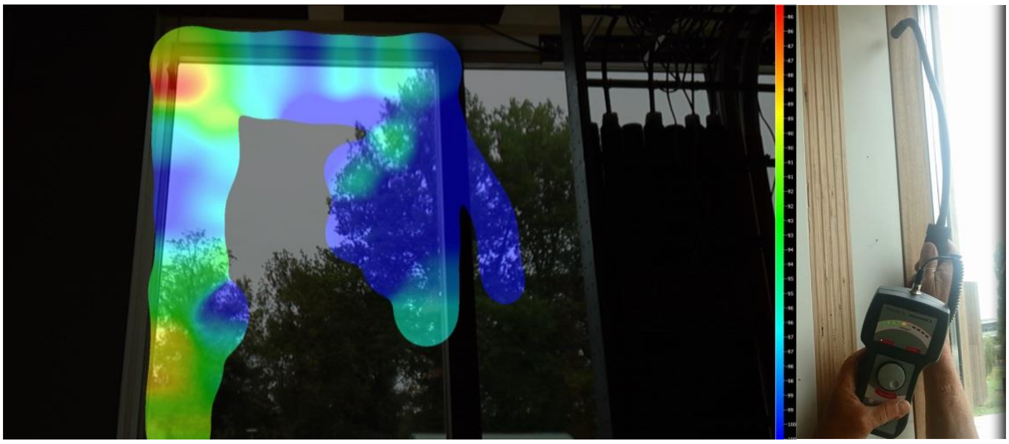


Figure 56: Ultragraphic and Ultrasonic measurement of the same situation

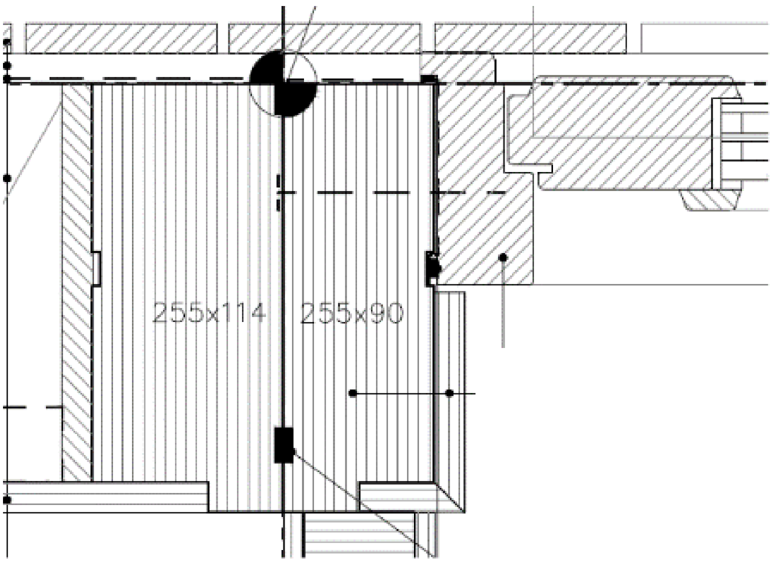


Figure 57a: Closer examination of the detail near the window frame

Figure 57b: Proof of the use of airtight sealant and the situation before finishing (not on the exact position of the air leak)

Cable entry through the floor

In the Green Village there are a lot of cables and ducts coming out of the ground and lead through the floor of the module. This is always a critical point for airtightness. Especially when the cables are close to each other and there is limited space to place the adhesive tape around it. Although it is expected that this will always be a weak point, with paying a little more attention the airtightness around the orange cables can be improved.

- Threshold: The difference in sound pressure level between the relative small hole near the orange cable entry (-86 dB illustrated as red in the image) and airtight places (-100dB illustrated as blue in the image) is below the threshold of 20dB (Figure 59).
- Action:
  - This air leak is relative small and does not demand extensive re-work. A little more attention to the connection of the adhesive tape to the orange cable will do.
  - Feedback to the design phase to come up with better solutions for cable and duct entries.

Figure 58: Cable and duct entry

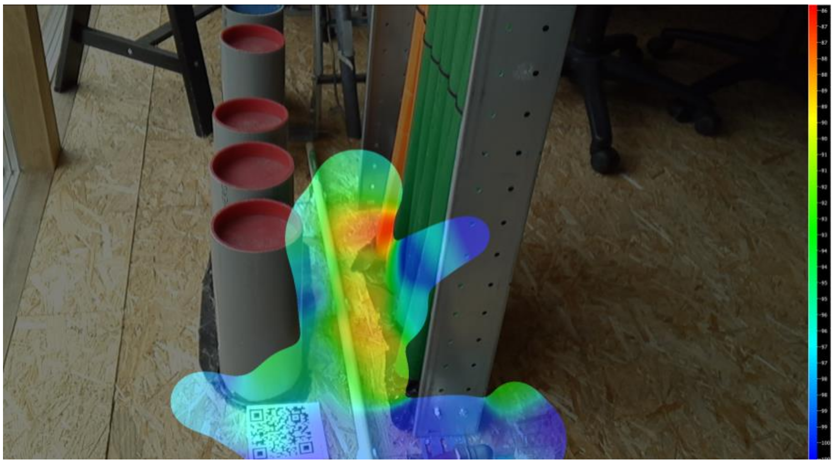


Figure 59: Ultragraphic of the cable entry

Figure 60: Detailed picture of the adhesive tape around the orange cable

Duct entry through the ceiling

A few ducts entry the ceiling / roof of the module. No airtightness cuff is used and we don't have the information how this entry is made airtight. The measurement shows a small air leakage near the duct. Attention should be paid to avoid such problems in the future.

- Threshold: The difference in sound pressure level between the relative small hole near the duct entry (-76 dB illustrated as red in the image) and airtight places (-88dB illustrated as blue in the image) is below the threshold of 20dB (62)
- Action:
  - This air leak is very small and does not demand re-work.
  - Feedback to the design phase to come up with better solutions for duct entries

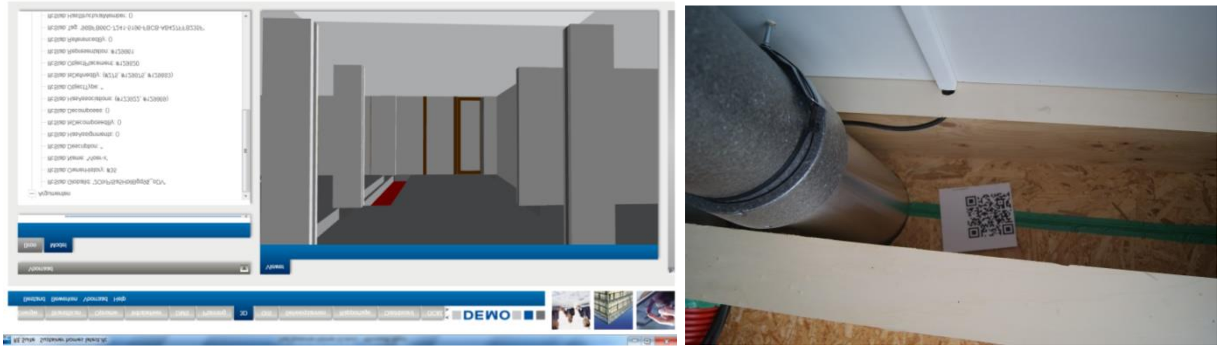


Figure 61: Duct entry ceiling/roof

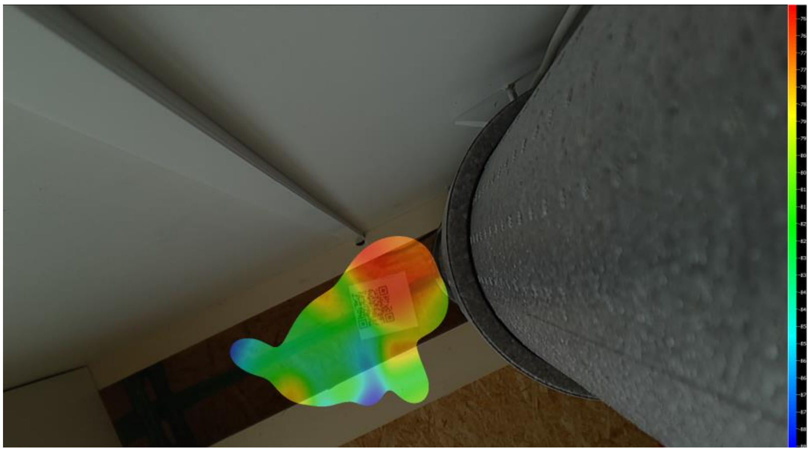


Figure 62: Ultragraphic of the duct entry

Conclusion of the ultrasound measurements

For research reasons we have carried out only a few samples and we did not check the whole building. The results of the samples show some minor air leakages, but all within the threshold.

The ultragraphic method (making the ultrasound visible) gives more information and makes it possible to compare the results with the threshold. The image of the tested area can be uploaded to the BIM-system. The setup of the ultragraphic method takes more time and the measurement itself is also more time consuming.

The ultrasonic method (making the ultrasound audible) gives limited information and it is not possible to compare the results with the threshold. For a first quick inspection or for excluding measurement errors it is valuable.

We advise to use the ultrasonic method to check all critical connections and entries and the ultragraphic for those connections and entries which shows possible problems during the ultrasonic method.

Blower door test

The final prove of the airtightness of a building is done with a blower door test. An essential condition for the blower door test is that the building envelope needs to be closed. Corrective measurements in case of air leakages are more difficult because it can only take place in the final stages of the building process.

The blower door test can take place at two stages:

- Before interior finishing (method B);
- After the complete building is ready.

An experienced advisor or trained user is needed to conduct the blower door test.

With a good instruction, a good execution including visual inspection and ultrasound inspection, it is to be expected that less problems will show up during the blower door test.

We advise to combine the Blower Door test with detecting the air leakages (smoke, IR).

- KPI: air-tightness
- Threshold – comparison of the results of the blower door test with the program of demands (qv10, n50 etc.)
- Evidence; Blower door report
- Action:

1. When the demanded airtightness is not met, air leakages has to be located and repaired;
2. Feedback has to be sent to involved parties to prevent such errors in the future;
3. The real measured airtightness (qv10, n50 etc.) can be used in the energy calculation program to recalculate the expected energy use.

The Blower Door test was not done for this test case.

Key Performance Indicators / metrics for measuring impacts

The Key Performance Indicators are mentioned above for each inspection or measurement. Only the blower door test gives a good indication of the unwanted infiltration or exfiltration through the building envelope. This measurement technique is for self-inspection less useful because it can only be done when the complete building envelope is closed. The blower door test gives us a figure about the infiltration/ exfiltration which can be used to calculate the energy loss caused by this.

From the program of demands for the building (e.g. n50/qv) we can calculate the allowed area of unwanted openings. But we don't accept any visible openings, so knowing the total allowed area of openings makes no sense for the visible inspection.

The ultrasound measurement technique gives us a valuable indication about the airtightness in an early stage of the building process. That makes this technique very fit for the self-inspection. But it does not give us exact figures we can use for further calculation of the energy performance.

3.3.2 Use case 3: Compare as-designed with as delivered and as-built situation (overall)

Use Case 5.3				INSITER INTUITIVE SELF-INSPECTION TECHNIQUES	
Compare as-designed situation with as-delivered and as-built					
Relevant Demonstrator		Sustainer Homes			
Responsible Insiter Parter		DMO			
	Description	**responsible partner**	**additional input**	**timeschedule**	**tools to be used in site testing**
Step 1	Design and production of modules	Sustainer Homes	n.a.	completed	n.a.
Step 2	Create BIM-model	RDF	DMO	in time	IFC-viewer
Step 3	Prepare BIM for on-site use and upload to server	RDF	na	in time	n.a.
Step 4	Upload relevant information to server	DMO, Sustainer Homes	Contractor (mounting crew and project manager)	in time	Insiter-methodology
Step 5	Step 1 Insiter methodology mapping	Contractor	Sustainer Homes, DMO	in time	QR-code when available
Step 6	Step 2 Insiter methodology checking of ordered components	Contractor	Sustainer Homes, DMO	in time	
Step 7	Step 3 Insiter methodology BIM for on-site construction	Contractor	Sustainer Homes, Insiter partners	n.a.	
Step 8	Step 4 Insiter methodology BIM-based AR	Contractor	Sustainer Homes, DMO,FHGIPA	in time	n.a.
Step 9	Step 6 Insiter methodology self-instruction	Contractor	Sustainer Homes, DMO	in time	See use case 5.1
Step 10	Step 7 Insiter methodology self-inspection	Contractor	Sustainer Homes, DMO	in time	See use case 5.2
Step 11	Step 8 Insiter methodology final check	Contractor	Sustainer Homes, DMO	n.a.	

Table 21: Use Case 3 Compare as-designed situation with as-delivered and as built

The use-case 3 compares the as-designed with the as-delivered and the as-built situation. The input from use-case 2 in respect to the visual inspection and the inspection with the ultrasonic measurement for airtightness can be used.

The Sustainer Home building on the grounds of the Technical University of Delft is a demonstration building. This means that not all aspects of the Dutch building code are applied to this building.

In the program of demands the quality performance for airtightness was mentioned as good, without any explanation what good exactly means.

Therefor we used the INSITER quality requirements as described for visual inspection and inspection with tools as described in use case 2. The results from the visual inspection and the inspection with the ultrasound measurement were according to the INSITER quality requirements. The final check on building level for airtightness (blower door) is not done. The INSITER consortium had not the resources to fulfil this.

Monitoring

The energy consumption and indoor climate Sustainer Homes demonstration case is very well monitored in the use phase.

Figure 63: Monitoring system for Sustainer Homes Office

To test the INSITER methodology we have had a focus on the single aspect of airtightness. The airtightness of the building envelope has an major impact on the energy efficiency of the building, acoustic performance, indoor air quality, fire safety and the risk of unwanted condensation in the structure. Therefore it is a good parameter to check the quality, energy efficiency and indoor climate but certainly not the only parameter.

Another aspect is that in the design phase no detailed energy calculation is made and no values are set for indoor air quality and temperature. For this reason it is not possible to compare the as-designed results with the as-is results.

To complete the Sustainer Homes demonstration case we will show the results of the Office Building for energy consumption, temperature and indoor-air quality.

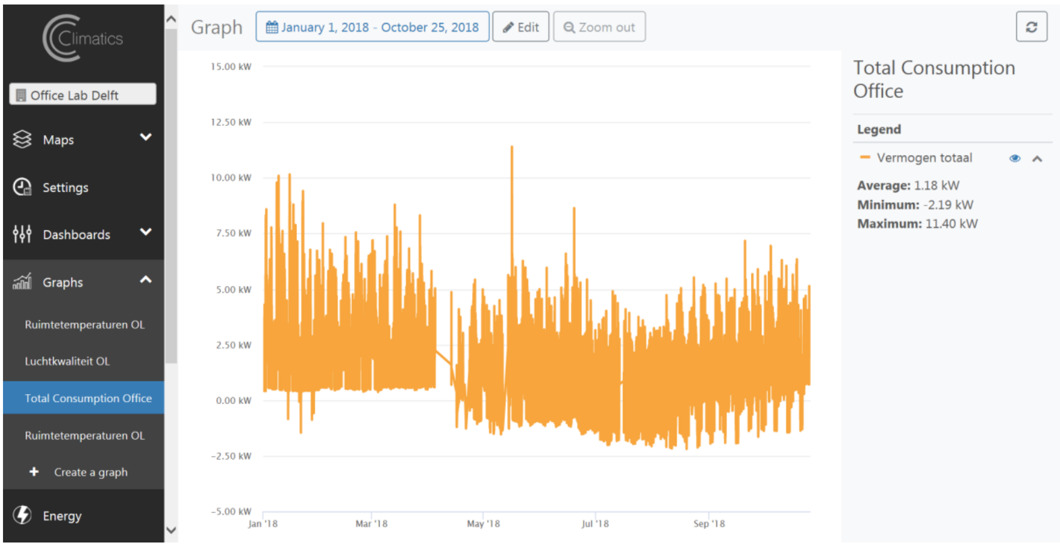


Figure 64: Energy consumption of Sustainer Homes Office building

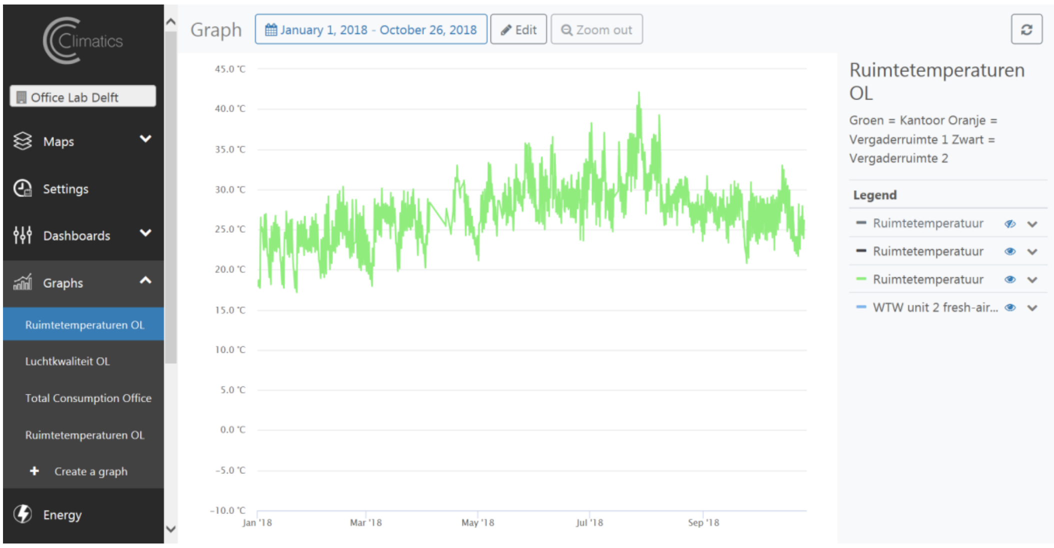


Figure 65: Room temperature of Sustainer Homes Office building

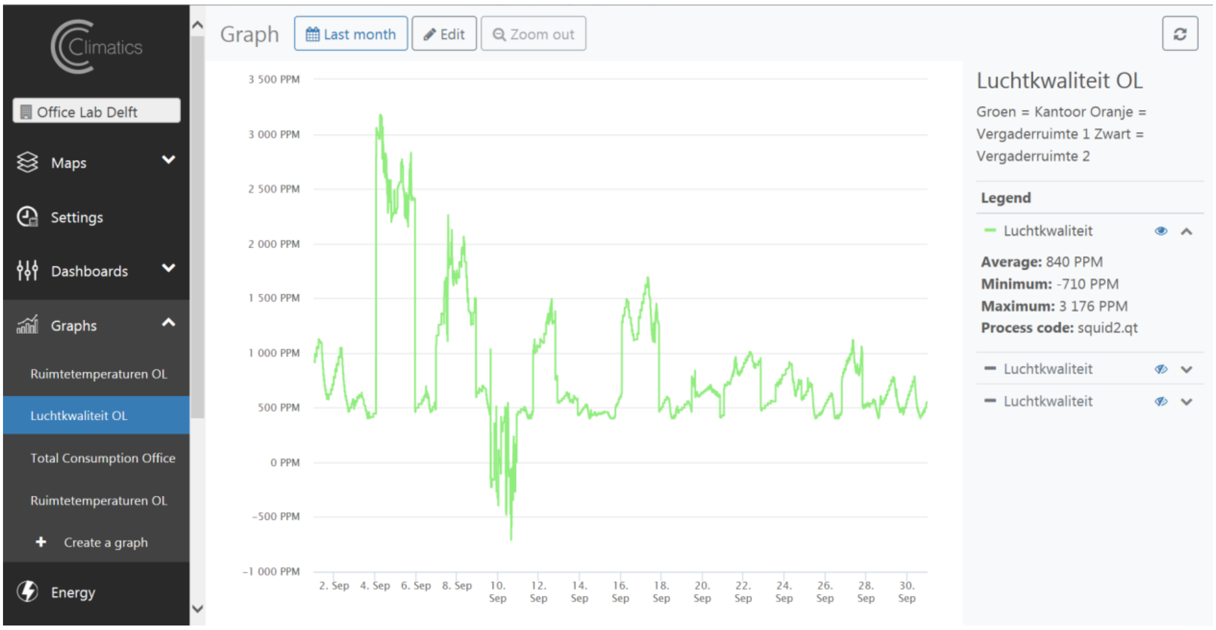


Figure 66: Air quality of Sustainer Homes Office building (September)

Conclusions

Compliance with Key Performance Indicators

The results of the ultrasonic measurements were compared with the threshold as mentioned in Deliverable 1.5 & 5.6. This gives us a qualitative impression of the airtightness quality. Suppose that the samples we have taken are representative for the whole building we can give a qualitative impression. If we were to reward the results on a five-

point scale (--, -, +/-, +, ++) then we give a met with a +.
The key performance indicators are of a higher level. Therefore, we have to conduct a blower door test to know the exact airtightness of the building envelope. The blower door test can only take place when the whole building envelope is airtight, and the installation is in place. This is at the end of the building process. The results of the blower door test (qv10, n50 etc.) can be used in energy calculation software.

Compliance with stakeholder requirements

The stakeholders, owner of the building and the supplier, want a good quality assurance. One of the most critical factors in prefab components is a good airtight connection of the elements and airtight lead through of ducts, pipes and cables. The toolbox meeting in advance and the extensive attention during the mounting of the elements took care of additional attention for a good quality of the work. This is all visually checked and documented with dozens of photos.
We believe that this attention results in a good airtightness of the building envelope, but we can’t prove this without blower door measurements. Those measurements did not take place anymore.

Improvement and lessons learned

Due to the early stage of this demonstration project the experiences during the project gave INSITER insight in the use of the INSITER methodology and tools. The lessons learned in this project are used to improve the methodology and tools.
We have seen that the building culture is not used to self-instruction and certainly not to self-inspection. The use of INSITER tools on site can only be successful when the craftsmen are aware of the importance of quality assurance. But even than the self-instruction and inspection should have a limited disturbance of the mounting work.
The visual inspection and the evaluation of the results of the visual inspection can be done by the craftsman. Measurement with equipment (in this case ultrasound) demands an advisor or an experienced user. The results of the ultrasound inspection can only be judged by an expert. We advise to involve the craftsmen in the results of the measurements to give feedback on the quality of their work.

4. Real demonstration case of refurbishment in Enschede, NL

4.1 Changes compared to the original plan described in D5.3

The Demo Case 3 Mobile inspection tool for post-renovation condition assessment as mentioned in D5.3 is integrated in the Demo Case 2 as step 5 Conduct visual on-site comparison with the BIM model.

4.2 Field validation / demonstration procedures for each use case

Introduction

The detailed description of Hogekamp in Enschede was provided in D5.3. In short, the demonstrator is an abandoned building of the University of Twente. Hogekamp was originally designed with no real Programme of Requirements to work from so the structural design had to be particularly flexible. This 'adaptable building' fulfilled its research and educational function for 40 years and nowadays is being renovated and transformed into a student housing (75%) and a hotel (25%). It was estimated that implementation of prefab solutions for the building's envelope and HVAC systems (Heating, Ventilation and Air Conditioning) and making use of the embodied energy can provide energy saving reaching 70% compared to the situation before the renovation. The prefab solutions, including façade panels but also units of kitchen and sanitary modules, will allow 50% time saving in the renovation process. Nowadays the energy label is G; the goal of the deep renovation is to improve the energy label to at least B (target A).

Figure 67: *Original building at first opening in 1965 (53 years ago) and existing situation (2016).*

This case study is conducted in a synergy with another Horizon 2020 project titled P2ENDURE (www.p2endure-project.eu), which is coordinated also by DEMO Consultants (Dr. Rizal Sebastian). The BIM model has been created as a part of the P2ENDURE project and shared with the INSITER consortium. During the renovation of the building - with the agreement from the building owner, project developer and contractor - a field testing will be organised for the purpose of the INSITER project. The results of the field testing will be presented in D5.5 (due in M45 – August 2018).

Figure 68: Current situation on-site from 14thNovember 2017: 1/ south corner – hotel part; 2/ south-east façade; 3/ north corner

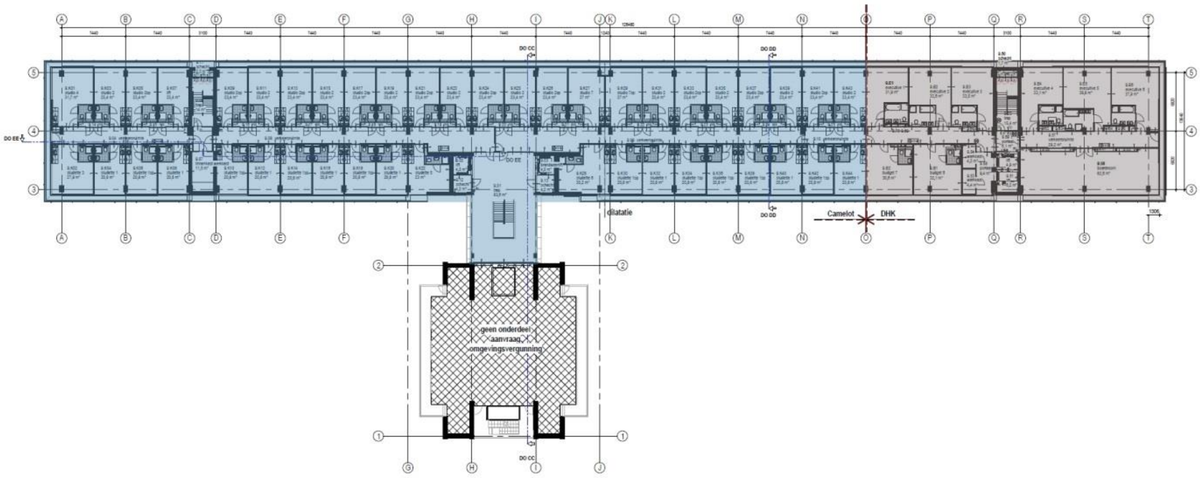


Figure 69: Floor plan of 1st-9th floors including division into the student housing (Camelot) and the hotel (DHK)

An update from the construction site

The deep renovation of the student housing in Enschede is executed as part of the P2ENDURE project, which promotes evidence-based innovative solutions of prefabricated Plug-and-Play systems. The following prefab retrofitting solutions are being implemented in the building:

- Installation of new building envelope
- Modular units of kitchens and bathrooms
- New MEP / HVAC systems

The construction, including demolition and remediation, has started in April 2017 and is scheduled to be completed in July 2018. From 1st September 2018 students will be able to move in and the hotel will start to receive first guests.
The façade panels of the student rooms are all placed. The ground floor facades are still open. The façade on the part of the building where the hotel is positioned will be placed soon.

Starting from the 9th (last) floor and proceeding downwards: 40 façade panels and 8 bathroom units are being installed per day. 4 mock-up rooms of the student apartments have been realized in September-November 2017.
The installation of prefabricated bathroom and kitchen pods in the demonstration case in Enschede will be followed by the installation of plumbing connections. Vertical connecting installations will be performed in a classical way on the spot.

Figure 70: Renovation of a student apartment; placing of a bathroom unit: 1/ state before renovation; 2/ placing walls; 3/ placing a bathroom unit; 4/ installation of the bathroom unit; 5/ painting – state after finishing renovation

Figure 71: Work progress on the installation of the bathroom units: the meter cabinet on different stages of completion

Natural (passive) ventilation will be used to provide high thermal comfort and adequate fresh air for the ventilated spaces, while having little or no energy use for active HVAC ventilation. Other benefits of choosing natural ventilation in modern buildings are improved indoor air quality (IEQ), reduction of greenhouse gas emissions or occupant control.

The ground floor area will be renovated as last in May-June 2018. This part will contain an entrance hall to the student complex with a show room as well as a hotel part with a conference centre and a restaurant.

Figure 72: Current state of the ground floor area

More technical drawings and pictures are available on the SharePoint in the following folder:
[link] > *Shared Documents* > *11 WP5* > *Enschede, NL*
(All the materials are property of Camelot Real Estate, not to be published without prior permission)

The following two chosen use cases for the INSITER storyboard are the main interventions within the deep renovation of the building in Enschede, resulting with the energy saving close to 70% in comparison with the existing building:

- Replacement of the façade with prefabricated panels
- Replacement of MEP / HVAC systems also as part of the prefabricated modules of the student apartments

The energy consumption of the Hogekamp building before renovation and in use as faculty building of the University:

- Electricity 104 kWh/m² y
- Heat 177 kWh/m² y
- Hot water 83 kWh/m² y

The total energy consumption for the building can be calculated:

- Total floor area 20296 m² = 7,387,774 kWh

The actual energy consumption before renovation is compared with the calculated primary energy consumption in pre-renovation scenario. The calculated value is 300 kWh/m²y. This is about 18 % less than the real value of 364 kWh/m²y. So the calculation gives a good indication.
The calculated value after renovation is 115 kWh/m² y. This is a saving of about 62% compared to the calculated value before renovation. (The energy analysis where performed by using a BIM-to-BEM methodology for calculation of building energy performance that is developed and tested in P2ENDURE; therefore, the results are just indicative and should be compare with the real energy consumption after renovation – that is not available yet)

At this stage of the project there are no KPI specifications and measurements available in relation to the actual building energy performance. The results of the field testing within the following use cases, including specific data related to the energy performance of the building envelope, will be presented in the D5.5 deliverable report (due in M45 – August 2018).

4.2.1 Use case 1: Building envelope – Inspection of deviations at the placement of new façade panels and windows

Storyboard: Check and approval of measured values (self-inspection at component level)

- The installed façade panels and windows in real live will be compared to the BIM model.
- Inaccuracies and defects will be identified using thermal scanning at critical joints in the façade system.
- Research question to be resolved: After field measurement, how to determine that the realised quality is acceptable / within the accepted tolerance; how to set the threshold?

It is scheduled to perform the following evaluations within this use case:

	Description	Responsible partner	Additional input	Time schedule	Tools to be used in the site testing
Step 1	Create BIM model	DMO (Camelot)	Demo case owner; P2ENDURE project	In time	IFC viewer
Step 2	Prepare the BIM model for on-site use	DMO (Camelot)	Demo case owner; P2ENDURE project	In time	IFC viewer
Step 3	Proceed with activities concerning on-site assembly of the panels to the façade	Assembler	N/A	In time	N/A
Step 4	Prepare procedure for on-site testing by thermal scanning for post-renovation inspection	UNIVPM	DMO	In time	INSITER guidelines
Step 5	Conduct visual on-site comparison with the BIM model	DMO	Demo case owner (Camelot)	14^{th} November 2017	IFC viewer, photo camera
Step 6	Perform thermal scanning to identify thermal bridges	UNIVPM	DMO	March 2018	Thermographic camera

Table 22: Data sheet use case 1 Hogekamp

The results of the on-site thermal scanning (step 6) will be presented in D5.5 (due in M45 – August 2018).

On-site comparison of the façade panels and windows with the BIM model

The aluminium window frames are executed within Kanweer RT6 series characterized by high water penetration resistance. Aluminium is a strong and relatively light material what makes it ideal for façade construction. The thin window frames ensure for maximum daylight. Thanks to the modular structure, the façade panels can be easily placed and interconnected with other modular systems.

Technical properties:

- Material: aluminium extrusion profile
- Alloy: EN AW 6060 T 66 according to EN 573 anodising quality
- Construction: symmetric 3-chamber system
- Frame depth: 62mm (can be adjusted depending on required strength)
- Wing depth: 70mm
- Glazing: solar control insulating glass HR++ (high efficiency glass – double-glazing fitted with an HR-coating on the inside of the air cavity); U=1.0 W/m^{2}K at cavity
- Glazing capacity: maximum 46/54mm

Performance description:

- Insulation value: U_f 2.24 W / m²K according to EN 10077-2
- Air tightness: Class 4 according to EN 12207
- Waterproofing: E 900 according to EN 12208
- Burglary-resistant: Class 2 or 3 according to EN 1627 to 1630 and NEN 5096
- Sound insulation: Maximum RW 47 (-1, -4) dB according to EN 717-1 and EN 140-3
- Wind velocity pressure: Qp=1.11 kN/m^2
- Pressure testing: 250 Pa (the wind and water tightness of doors can be guaranteed up to 150 Pa)

Montage: the aluminium frames are placed in a wooden frame, which are supplied and installed by Alkondor with a minimum thickness of 25 mm due to the screw-in depth. The final thickness is determined by Alkondor. The frame must be sufficiently strong and rigid according to NEN-EN 1991-1-1 (+NB) and NEN-EN 1991-1-4 (+NB) to be able to drain the loads. It must also enable air- and watertight, flat, angle and twist-free connection of the façade elements.

Figure 73: Work progress on installation of the façade panels: 1/ placing wooden frames; 2/ placing aluminium frames; 3/ aluminium frames; 4/ placing panels; 5/ final result

Figure 74: Work progress on the window sill at connection with the bitumen finishing

There are three BIM models available for the Enschede demonstration case:

- Situation after demolition and before renovation
- Renovation design situation
- MEP / HVAC systems

In the 3D models all the main façade elements are included. The small elements and materials related to the installation are missing, like the mounting plates for the window panels, as shown in the pictures below.

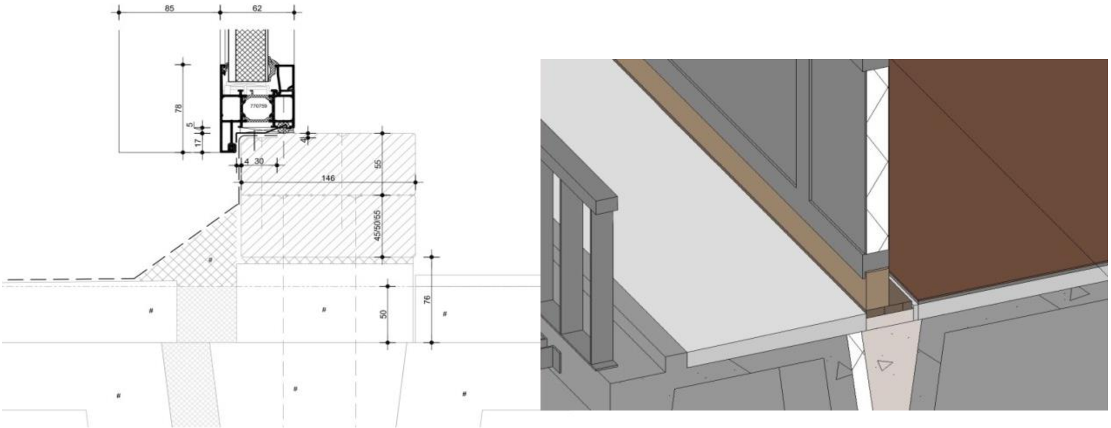


Figure 75: The level of detail of the BIM model on the example of the section of the window frame

Figure 76: Comparisons between real live situation and the BIM model: general outside and inside views on the façade panels

Validation

Even when modern technology and thermal rehabilitation measures are well implemented, thermal bridges in the building's envelope remain a weak part of the construction. More accurate results of the façade's thermal properties will be assessed by performing thermal scanning.

The performance of the windows, regarding energy efficiency, depends also on proper installation. By performing thermal scanning also the manual installation will be revised, if the work done on-site influenced the quality of the façade. The results of the on-site thermal campaign will be presented in the D5.5 report.

Thermal Bridge identification before project delivery

After the installation of prefab solution façade panels, it is very important to verify the connection between these elements to avoid energy loss. Figure 78 shows the concept of Plug-and -Play panels. Each connection, joint or support could generate thermal bridges and these could have effect on the envelope's thermal performance.

Figure 77: Comparisons between real live situation and the BIM model: corners in a corner room and middle room

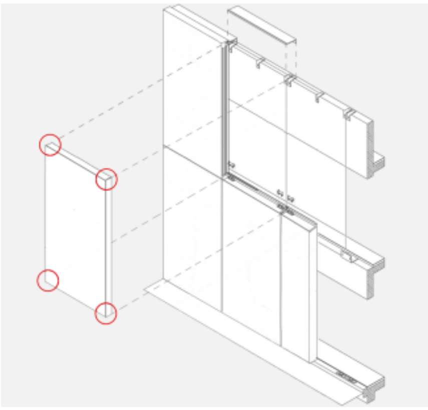


Figure 78: Plug and play panels, critical junction

In this report methodology for thermal bridges identification of the Hogekamp's building envelope will be described. As mentioned before, at this point there are no KPI specifications and measurements available to indicate energy performance improvements of the building envelope. The deliverable report D5.5 will present the results achieved during the thermal test campaign on Hogekamp in Enschede, which is planned to take place at the beginning of 2018. The building envelope thermal measurements will be carried out with the purpose to show heating dispersion of the external facades.

The INSITER procedure for the quantification of the effect of thermal bridges in terms of building envelope thermal transmittance is based on infrared camera measurements. This method will be applied to a room of the University of Twente building. The room selected is room 1.K38 located at the first floor of the building. The room has one external wall and three internal walls. Only the external walls will be monitored using sequential measurements at different positions of the infrared camera as sketched in Figure 79 where a provisional experimental set-up is drafted.

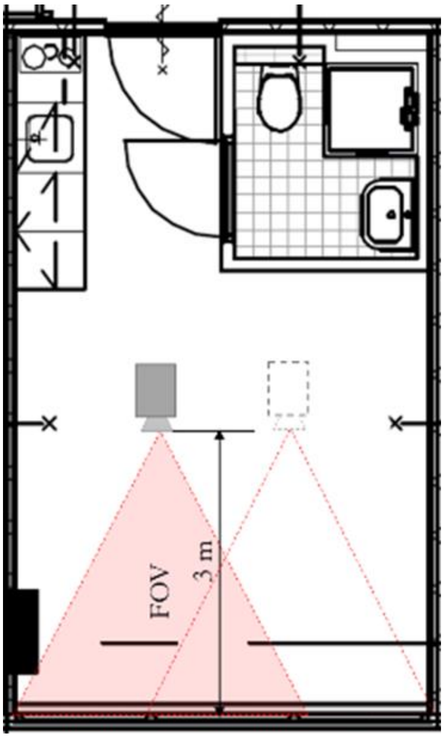


Figure 79: Room 1.K38 with area of 20.6 m2 and size 3575 x 5772 x 3.3 m

Procedure for the identification of thermal bridges (according to the guidelines described in D5.1, Section 3.2; D5.2, Section 2.1.2; and D2.3, Section 3.2):

- Inspect the condition of the room and environment. There must be no rain during the measurement neither in the 12 hours before the survey.
- Identify the wall under test by QR-coding.
- Install thermal camera inside the room in front of the wall. The distance of the camera from the wall is a compromise between the Field of view (FOV) of the thermal camera and the surface of the room. The farther from the wall is positioned the camera the larger area can be framed, but that distance is limited by the size of the room. Four measurement positions are needed to cover the whole surface of the two external walls. In Table 1 the main characteristics of the adopted infrared camera are reported.

Type of detector	microbolometer
Spectral range	7 -14 µm
Temperature resolution	0.03 °K
Spatial resolution	1024x768 pixels
Optics	Wide angle lens 15 mm
Field of View (FOV)	≥ 3.4x2.6 m at 3 m distance

Table 23: *Thermal camera characteristics*

- Verify that a thermal gradient of about 10°C between inside and outside exists. Usually a good insulated facade guarantees this thermal gradient, otherwise the room must be conditioned to detect thermal bridges. Infrared camera or additional thermal sensors can be used to estimate internal and external temperature.
- Estimate the emissivity of each surface framed by the infrared camera.
- Quantify the environmental reflected temperature.
- Acquire and store the thermal maps in a repository folder (e.g. the BIM model of the building).

Procedure for the quantification of the thermal bridges (according to the guidelines described in D2.3, Section 3.2 and BRE Information Paper IP 1/06, 'Assessing the effects of thermal bridging at junctions and around openings'):

Thermal bridge represents the transmittance of an area where the thermal properties are significantly different from the rest of the element. Consequently, the temperature in this area, when a thermal gradient exists between the two surfaces of the element, differs with respect to the sound area (where no thermal bridges are existent). Quantify the effect of thermal bridges in the whole element transmittance is an important issue.

A parameter for the assessment if a thermal bridge affect the thermal transmittance of a building element is defined in the BRE Information Paper IP 1/06, 'Assessing the effects of thermal bridging at junctions and around openings' which makes also recommendations for the limits of that parameter.

Such parameter is defined as Thermal Index, TI, (also known as Surface Temperature Factor) which is the following ratio:

$$TI = \frac{(Tsi - To)}{(T_{AI} - T_O)} \quad (1)$$

where:

T_{SI} = temperature of the anomaly (measured by the infrared camera on the area interested by the thermal bridge)

T_O = external air temperature.

T_{AI} = internal air temperature, i.e. the "ambient temperature".

The limits fixed by the BRE Information Paper IP 1/06 are:

0.75 in dwellings

0.5 in offices and shops.

If TI is lower than those limits it is likely that condensation will form on the surface at some time in a typical year.

If only a small portion of the structure has a TI below the threshold that thermal bridge cannot compromise the global thermal transmission of the building element. It is important, then, to estimate the influence level of the thermal bridge on the element, by calculating the percentage surface affected by the thermal bridge with respect to the total area of the element. A procedure has been described in D2.3, Section 3.2, where it has been defined the incidence factor of the thermal bridge I_{tb} as the ratio between the heat flowing in real conditions, when a thermal bridge exists in the wall, and the heat flowing in absence of the thermal bridge:

$$I_{tb} = \frac{\sum_{p=1}^{N}(T_{AI} - T_{p\_is})}{N * (T_{AI} - T_{1D\_is})} \quad (2)$$

where:

T_{p_is}= temperature at each pixel of the camera, where p is the current pixel which goes from 1 to N (N number of pixels)

T_{1D_is}= temperature in the sound area (not affected by the thermal bridge)

T_{AI} = internal air temperature

The thermal transmittance of the element in the presence of the thermal bridge is given by the thermal ideal transmittance in the absence of the thermal bridge (U_{1d} or thermal transmittance of the sound area) weighted with the incidence factor I_{tb}.

$$U = U_{1d} * I_{tb} \quad (3)$$

4.2.2 Use case 2: MEP system – AR on-site simulation at the assembly of a part of the new MEP system

HVAC systems installed in the existing buildings are often difficult to retrofit since the components of installations as part of a system are spread through the whole building in different spaces and in some cases have indoor and outdoor components in floors and ceilings. On the other hand, considering building's deep retrofits decision on improving consuming HVAC system can significantly contribute to overall building's energy saving. The aim of the demonstration is to propose efficient design and installation process with minimizing potential errors by using the INSITER tools, in this case study, oriented to the accuracy of BIM modelled MEP components or retrofit elements.

Storyboard: Check of installation quality (self-inspection at system level)

- Modelling the MEP system of the new situation in BIM (by Camelot; in synergy with P2ENDURE project).
- Checking the BIM model of the MEP system by virtual clash detection.
- Preparing BIM-based AR visualization of the new MEP system.
- On-site test deployment of AR for visual comparison between BIM model and realization of parts of the MEP system

It is scheduled to perform the following evaluations within this use case:

	Description	Responsible partner	Additional input	Time schedule	Tools to be used in the site testing
Step 1	Create BIM model incl. MEP systems	DMO (Camelot)	Demo case owner; P2ENDURE project	In time	IFC viewer
Step 2	Upload BIM model to Navis Works	HVC	N/A	In time	N/A
Step 3	Clash Detection Definitions and Preparation of the BIM model	HVC	N/A	In time	N/A
Step 4	Perform clash detection by checking all MEP trades	HVC	N/A	In time	N/A
Step 5	Create DCS (Design Coordination System)	HVC	N/A	In time	N/A
Step 6	Create a file of clash tubes	HVC	N/A	In time	N/A
Step 7	Provide an input to FHGIPA	HVC	FHGIPA	In progress	N/A
Step 8	Prepare BIM-based AR visualization of the new MEP systems	FHGIPA	HVC, DMO (Camelot)	November 2018	N/A
Step 9	Test AR on-site for visual comparison between BIM model and realization of parts of the MEP system	FHGIPA	HVC, DMO (Camelot)	December 2018 and May 2018	INSITER AR with MS HoloLens

Table 24: Data sheet use case 2 Hogekamp

The results of the on-site testing of the AR with HoloLens (step 9) will be presented in D5.5 (due in M45 – August 2018).

Clash Detection

Regarding INSITER´s demonstrator project Hogekamp, Enschede (NL) the validation method of clash detection will be performed. Based on models created within P2ENDURE project INSITER´s eight-step methodology has been applied.

The general process of performing clash detection is described in the following image. Regarding the Hogekamp project all trade models have been provided in three files: an architectural model, a structural model and an MEP model (incl. the trades HVAC, SAN, HYD, MISC – undefined MEP objects).

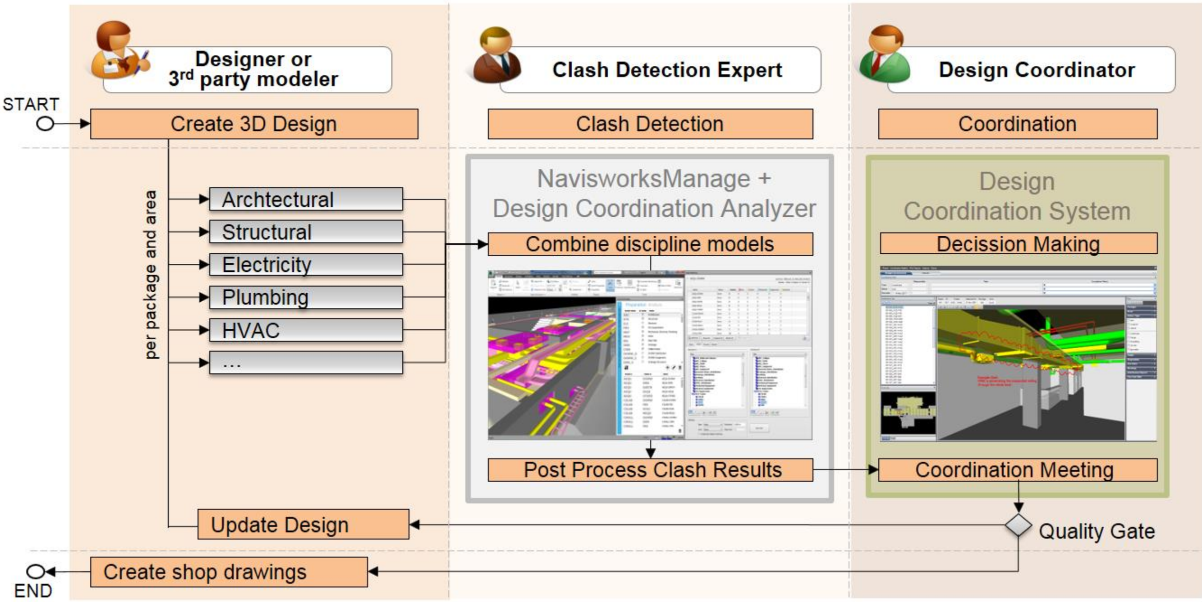


Figure 80: General process of performing clash detection

First step to perform clash detection is to consolidate all those filed in Navisworks and to purge to models for further processing. This means to hide those elements, which are not required for the specific clash run and to apply a colour coding to make the clash detection process itself as well as the coordination meetings later on easier.

To perform the clash detection ViCon´s Design Coordination Analyzer (DCA) will be used. This plugin to Autodesk´s Navisworks eases the process of clash detection by automatically generating clash batches, guiding the user through the whole clash detection process and to store the results of the geometrical analysis to be used in the Design Coordination System (DCS).

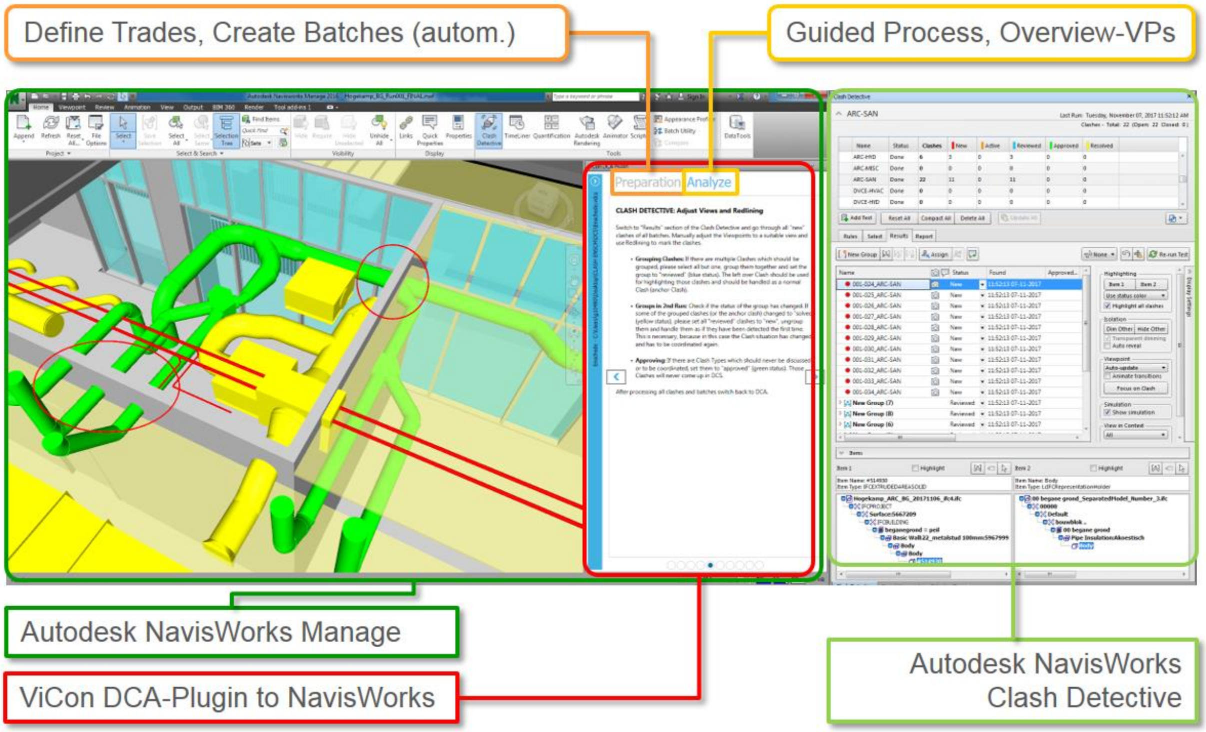


Figure81a: The user interface of Navisworks and the DCA plugin

After identification of the relevant clashes, which have to be coordinated before the construction process can start, the results of the clash run will be provided to the coordination team in the Design Coordination System (DCS). This tool provides functionalities to manage communication between the responsible persons for the trades, to coordinate the trades and write down tasks to solve the identified conflicts, and to report the conflicts as well as the coordination information in several reporting formats.

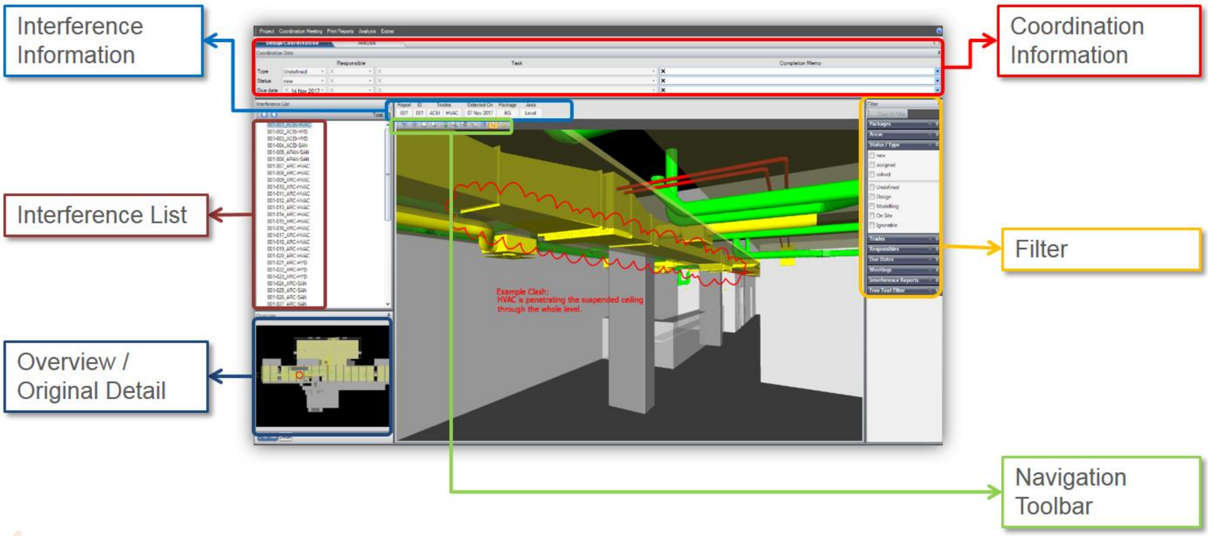


Figure 81b: The user interface of the Design Coordination System

There are three different kinds of reports available to be created out of the DCA:

- Executive Report
  This report gives on overview of the identified clashes, the status of those clashes and how many clashes are related to specific trades

- Individual Selection Report
  This report let the user filter for specific kind of conflicts and to just report those filtered clashes. With this report it is possible to create a trade-specific report to forward to the responsible designer.

- Meeting report
  This report provides information about all issues, which have been discussed and coordinated within a specific coordination meeting. This report is intended to quickly forward coordination information to be incorporated into the current design.

By using the method of 3D clash detection it is intended to speed up the design coordination process and to provide a well-coordinated design.

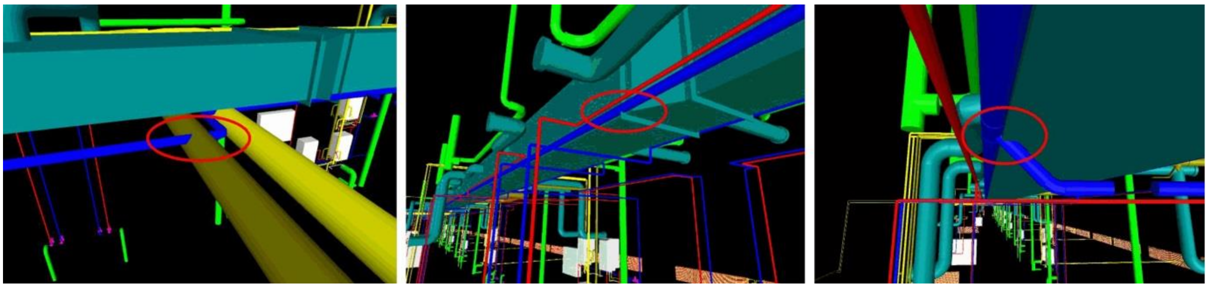


Figure 82: Examples of detected clashed in the DCS (Design Coordination System)

Application of Augmented Reality (AR)

In addition to the description in D5.3, the application of the INSITER AR solution on-site has been further refined according to the Hogekamp Enschede Use Case. During the construction of the new MEP system, the AR application will be applied within the use case by the architect and construction engineers with focus on the efficient design and construction consistency of MEP systems and HVAC elements.

Prior to the application of the INSITER AR solutions, related 3D BIM MEP data of the to-be target state has to be available or generated by BIM manager according to the new to be installed MEP building elements components.

The main steps concerning the application of AR for Hogekamp Enschede MEP systems are:

- Revision and Validation of BIM model incl. MEP systems for Hogekamp Enschede Use Case
- Preparation of BIM-based AR visualization of the new MEP systems
- Apply AR on-site for visual comparison between BIM model and realization of parts of the MEP system
- Thus the following sub steps are performed:
    - Retrieval of modelled 3D BIM data: Retrieval of BIM models concerning to-be situation, selection of BIM model objects for current viewpoint.
    - Set up AR Scene: Set up of tracking system application initialization, application of MS HoloLens and start of spatial mapping and 3D environment tracking
    - Start BIM 3D data visualization of elements to be installed or evaluated within AR application for visual comparison.
    - Conduct construction work according to building elements evaluation

During the application of the developed INSITER AR solution for Hogekamp Enschede the focus is on visual inspection of the MEP installation work using “hands-free” AR with the MS HoloLens. Besides the comprehensive INSITER AR solution for tablet computers, here the Microsoft HoloLens, based on the Windows Mixed Reality (WMR) platform is applied to develop and provide a “hands-free” AR application with the use of head mounted mixed reality see through technology in combination with spatial mapping and object tracking. The developed AR prototype will enable detailed 3D scenes evaluation for the Hogekamp MEP systems. Workers on-site can visualize is-situ which elements have e.g. to be attached, installed or removed with AR for Hogekamp Enschede refurbishment works or MEP installations. Also project managers can monitor the installation work on-site and check if new MEP systems are correctly installed.
The focus will be on a dedicated section of the building, where MEP installation will take place in December 2017 - January 2018. The following pictures present the corresponding section of the BIM model and details of the MEP systems of the bathroom unit:

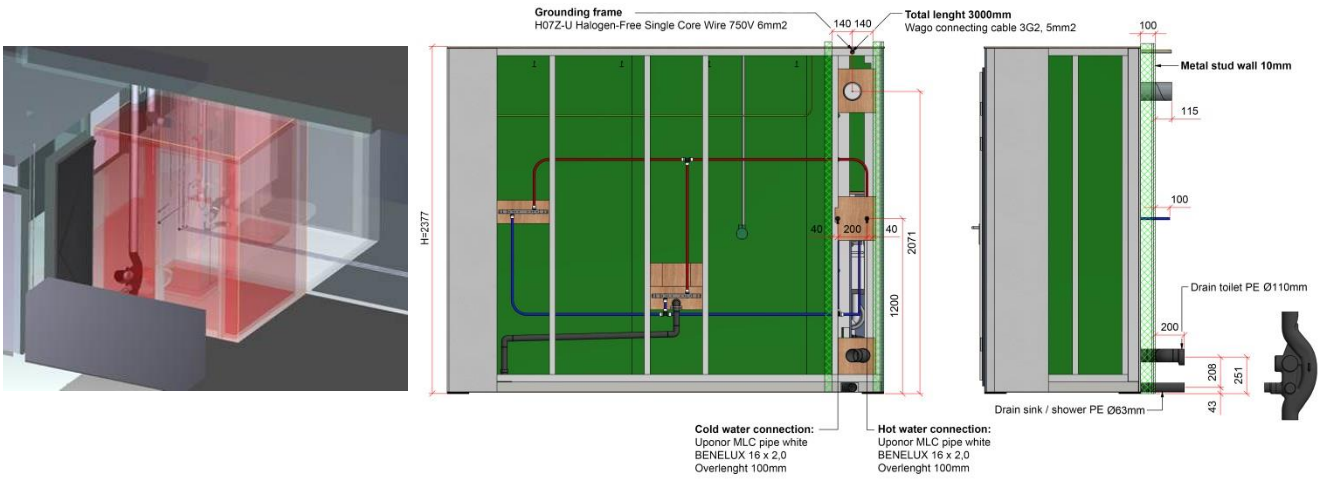


Figure 83: Targeted to-be situation as BIM illustration images and detail of the bathroom unit

Figure 84: Visual comparison example between BIM-based MEP model and the planned to-be target state and installation of the MEP system to be conducted at Fraunhofer example building with MS HoloLens.

4.3 Real measurements values / demonstration results from each use case

Introduction and objectives

Purpose of the demo and target group

The purpose of the first demonstration is to verify the connection between the prefab façade elements and the original construction of the building to avoid energy loss. The identification of thermal bridges will be described. The information is important for the contractor and the workers on site (mounting crew of the façade elements): firstly, to repair the deficiencies and secondly, to take action in order to prevent those deficiencies in the future. Depending on the failures the feedback of the findings will go to all involved parties to improve the product, the design or process.

The purpose of the second demonstration is to propose efficient design and installation process with minimalizing potential errors by using the INSITER tools. This use case-study is orientated to the accuracy of BIM modelled MEP-components or retrofit components. The clash detection is mainly directed on the design phase and important for the contractor, the installer and other subcontractors.

Description of the demonstration building

The demonstration case of Hogekamp in Enschede is the former faculty building of Electrical Engineering and Applied Physics. After some years of vacancy, it is currently being transformed into a building for student housing, a hotel and a congress centre. The transformed building will consist of 445 studios for students and a new conference hotel with 72 hotel rooms and associated conference rooms. The focus of the demonstration project is on the student housing.

For the transformation, prefab solutions are applied for the façade, kitchen and bathroom.

Figure 85: Hogekamp building, mock-up student room

Figure 86: Back site of prefabricated bathroom student room

The main goals of this demonstration case were testing the right placement of the new prefabricated façade elements and the use of augmented reality for the new MEP-system. The results of the demonstration cases were presented during the stakeholders meeting in Enschede, in the Netherlands on the 28th May 2018.

Contribution of partners

The contribution of the partners and their role in the two use cases for Hogekamp is described in *Table 25: Overview Use case 1 Hogekamp,* activity list

and Table 26: Overview Use case 2 Hogekamp, activity list applied steps 4, 5 and 6 of INSITER 8-step methodology.

Description of set of demonstrations

Two use-cases were defined for the Hogekamp demonstration case:

1. Building envelope – Inspection of deviations or flaws at the placement of new façade panels and windows
   Storyboard: Check and approval of measured values (self-inspection at component level)
2. MEP system – Augmented Reality on-site simulation at the assembly / installation of a part of the new MEP system
   Storyboard: Check of installation quality (self-inspection at system level)

Use case 1: Building envelope – Inspection of deviations or flaws at the placement of new façade panels and windows

Storyboard: Check and approval of measured values (self-inspection at component level)

1. The installed façade panels and windows in real live will be compared to the BIM model. See link for short demonstration.
2. Inaccuracies and defects will be identified using thermal scanning at critical joints in the façade system.
3. Research question to be resolved: After field measurement, how to determine that the realised quality is acceptable / within the accepted tolerance; how to set the threshold?

It is scheduled to perform the following evaluations within this use case:

	Description	Responsible partner	Additional input	Time schedule	Tools to be used in the site testing
Step 1	Create BIM model	DMO (Camelot)	Demo case owner; P2ENDURE project	In time	IFC viewer
Step 2	Prepare the BIM model for on-site use	DMO (Camelot)	Demo case owner; P2ENDURE project	In time	IFC viewer
Step 3	Proceed with activities concerning on-site assembly of the panels to the façade	Assembler	N/A	In time	N/A
Step 4	Prepare procedure for on-site testing by thermal scanning for post-renovation inspection	UNIVPM	DMO	In time	INSITER guidelines
Step 5	Conduct visual on-site comparison with the BIM model	DMO	Demo case owner (Camelot)	14th November 2017	IFC viewer, photo camera
Step 6	Perform thermal scanning to identify thermal bridges	UNIVPM	DMO	26th - 28th March 2018	Thermographic camera

Table 25: Overview Use case 1 Hogekamp, activity list

Step 1 until 5 is already well documented in D5.4.

Step 6: The procedure for the identification of thermal bridges is described in D5.4. In this delivery we will present more in depth the results of the measurements.

Thermal scanning can identify inaccuracies and defects at critical joints in the façade system. Thresholds have to be set to determine that the realised quality meets the requirements. Methods to set threshold to localise thermal bridges and to estimate their influence on the building energy performances have been described in D1.5.

Use case 2: MEP system – AR on-site simulation at the assembly / installation of a part of the new MEP system

Storyboard: Check of installation quality (self-inspection at system level)

- Modelling the MEP system of the new situation in BIM (by Camelot; in synergy with P2ENDURE project).
- Checking the BIM model of the MEP system by virtual clash detection.
- Preparing BIM-based AR visualization of the new MEP system.
- On-site test deployment of AR for visual comparison between BIM model and realization of parts of the MEP system

It is scheduled to perform the following evaluations within this use case:

	Description	Responsible partner	Additional input	Time schedule	Tools to be used in the site testing
Step 1	Create BIM model incl. MEP systems	DMO (Camelot)	Demo case owner; P2ENDURE project	In time	IFC viewer
Step 2	Upload BIM model to Navis Works	HVC	N/A	In time	N/A
Step 3	Clash Detection Definitions and Preparation of the BIM model	HVC	N/A	In time	N/A
Step 4	Perform clash detection by checking all MEP trades	HVC	N/A	In time	N/A
Step 5	Create DCS (Design Coordination System)	HVC	N/A	In time	N/A
Step 6	Create a file of clash cubes	HVC	N/A	In time	N/A
Step 7	Provide an input to FHGIPA	HVC	FHGIPA	10-2017	N/A
Step 8	Prepare BIM-based AR visualization of the new MEP systems	FHGIPA	HVC, DMO (Camelot)	11-2017	N/A
Step 9	Test AR on-site for visual comparison between BIM model and realization of parts of the MEP system	FHGIPA	HVC, DMO (Camelot)	12-2017and 05-2018	INSITER AR with MS HoloLens

Table 26: Overview Use case 2 Hogekamp, activity list applied steps 4, 5 and 6 of INSITER 8-step methodology

Connection with other work packages

The results of this work package are the collection of the input from all the work packages about the method, the hardware, the software and BIM. The Hogekamp demonstration project is described in delivery D5.3 and D5.4.

- Use case 1 Building envelope – Inspection of deviations or flaws at the placement of new façade panels and windows has a connection with **D1.5 Measuring and diagnosis solutions for inspecting building components**. The tools are explained in delivery D2.3.
- Use case 2 MEP-system – Augmented reality has a connection with **D2.2 Robust and practical solutions of Augmented Reality for construction sites**. The tools are explained in deliverable **D4.2 Model Checking, Clash Detection and Value Engineering.**

4.3.1 Use case 1: Building envelope – Inspection of deviations at the placement of new façade panels and windows

The measurement campaign has been performed in March 26-28, 2018 by UNIVPM with the aim to evaluate, using the tools developed in INSITER project, thermal issue on the façade system. In particular, thermal bridges of the façade panels have been defined, according to the limits fixed by the BRE Information Paper IP 1/06.
Before describing the thermal bridges identification and localization procedure and the post-processing stage, the technical properties of the replaced façade panels have been identified.

Technical properties:

- Material: aluminium extrusion profile
- Alloy: EN AW 6060 T 66 according to EN 573 anodising quality
- Construction: symmetric 3-chamber system
- Frame depth: 62 mm (can be adjusted depending on required strength)
- Wing depth: 70 mm
- Glazing: solar control insulating glass HR++ (high efficiency glass – double-glazing fitted with an HR-coating on the inside of the air cavity); U = 1.0 W/m^2K at cavity
- Glazing capacity: maximum 46/54mm

Performance description:

- Insulation value: U_f = 2.24 W / m^2K according to EN 10077-2
- Air tightness: Class 4 according to EN 12207
- Waterproofing: E 900 according to EN 12208
- Burglary-resistant: Class 2 or 3 according to EN 1627 to 1630 and NEN 5096
- Sound insulation: Maximum R_W = 47 (-1, -4) dB according to EN 717-1 and EN 140-3
- Wind velocity pressure: Q_p = 1.11 kN/m^2
- Pressure testing: 250 Pa (the wind and water tightness of doors can be guaranteed up to 150 Pa).

Thermograms of the façade system of the building were acquired with the Infrared Camera Series VarioCAM HD head 980 (Infraec) (see *table below*), which is able to measure envelope emissivity distribution.

InfraTec Variocam HD 980 optical specifications:	
Focal Length (f) [mm]	15
*IFOV (*Instantaneous Field of View*) [mrad]*	1.7
Pixel dimension (Δp) [μm]	17
Horizontal number of pixel (p_h)	1024
Vertical number of pixel (p_v)	768

Table 27: Thermal camera specifications

Only one room has been tested to monitor the efficiency of the façade, specifically room K38, which is a third-floor unfurnished room with heating systems working. In Figure 87 and 88, the room is highlighted in blue in the relative floor of the elevation. In addition, orientation and geographical coordinates have been registered for the façade element under investigation in order to make possible the integration with the AR:

- Azimuth = 300°
- N 52°14'50''   E 6°50'58''

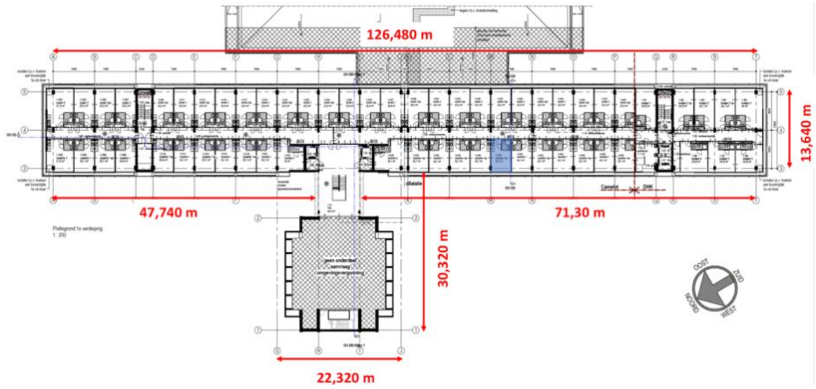


Figure 87: 3rd floor building plan with the analysed room K38

Figure 88: 3rd floor building elevation

The thermal camera has been placed inside the room in front of the glazed façade, at such a distance to frame the required field. In addition, a smartphone was used to capture the same frame of the thermal camera (see Figure 89), with the help of a suitable positioning system. Hence, one thermal image and one visible photo were stored.
After a preliminary analysis, it has been evidenced that the glazed façade does not present thermal bridges that can influence the thermal efficiency of the room, and therefore it has been decided to reproduce an artificial thermal bridge by slightly opening the central window.

Two different case studies will be thus reported:

1. Façade system completely closed;
2. Façade system with a small amount of leakage through the window sealing, obtained by opening the central window of just few millimetres, in order to simulate thermal bridges in a feasible situation when the building is in use.

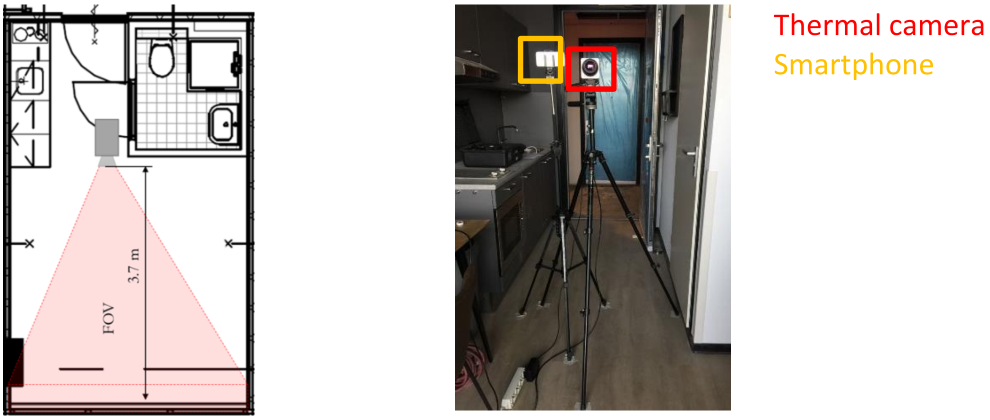


Figure 89: Instrumentation location

Test results

Figure 90 and Figure 91 show the two images, thermogram and visible. Figure 92 evidences a strong distortion of the thermal image due to the wide-angle lens mounted on the thermal camera to increase its field of view and to allow framing the entire glazed wall of the room. Consequently, the distorted image has been processed with a dedicated MATLAB code (see Figure 92) suitable for straigthening the image itself. The undistorted thermogram has been then superimposed into the visible image (see Figure 93), in order to easily locate temperature inhomogeneity in space.

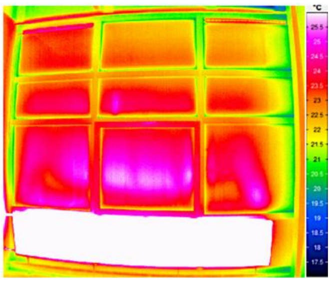


Figure 90: Distorted IR image-Window closed

Figure 91: Visible image-Window closed

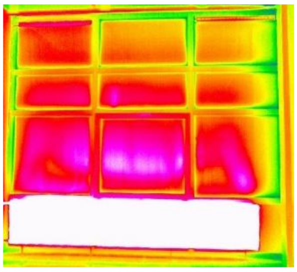


Figure 92: Undistorted IR image-Window closed

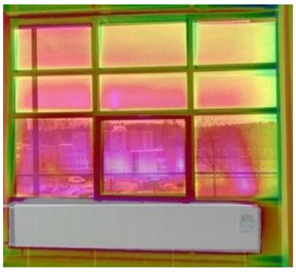


Figure 93: Overlapping - Window closed

Since the thermal gradient between interior and exterior environment, was more than 10°C, the Thermal Index (TI, see D1.5) was calculated, in order to localize the façade areas of leakage, thermal bridging or, in general, areas of anomalous surface temperature patterns. According to BRE Information Paper IP 1/06, if TI is less than 0.75 (threshold fixed in dwellings), it is likely that condensation will form on the surface at some time in a typical year. Hence, a figure showing the TI map was generated (Figure Figure 94). The temperature scale varies from 0 (“cold”) to 1 (“warm”), according to the fixed threshold (0.75). TI is defined as:

$$TI = \frac{(T_{SI} - T_O)}{(T_{AI} - T_O)} \quad (1)$$

Where:

T_{SI} = Temperature of the anomaly (°C) measured by the infrared camera on the area interested by the thermal bridge;

T_O = External temperature (°C);

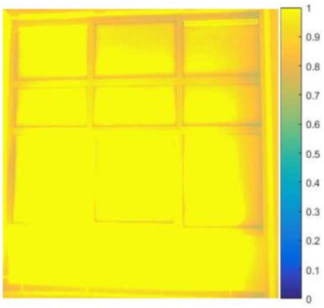


Figure 94: Thermal Index distribution map - Window closed

T_{AI} = Internal "ambient temperature" (°C).

Then, the Thermal Index image has been binarized, according to the fixed threshold (0.75), in order to easily visualize only the thermal anomalies. In the binarization post-processing, pixels with TI<0.75 are set to red, while pixels with TI≥0.75 are set to transparent. The binarized image has been overlapped to the visible photo of the façade system, as shown in Figure 95.

Figure 95: Binarized Thermal Index image - Window closed

Figure 96 and Figure 97 prove that no significant thermal anomalies/leakages occur in the glazed façade of room K38. Only small portions of the upper and lower right corner are red (see Figure 95) and, due to their very limited extension, they cannot affect the energy efficiency of the room. Thus, a thermal bridge has been simulated by opening the window of the room glazed façade. Before starting the measurement, the central window was left open for at least 15 minutes, in order to yield stable temperature conditions and allow the surface to cool. The already described procedure has been applied. In Figure 96 the thermogram is reported, with the temperatures scale, and in 97, the superimposition of the undistorted thermal image and the visible one is shown.

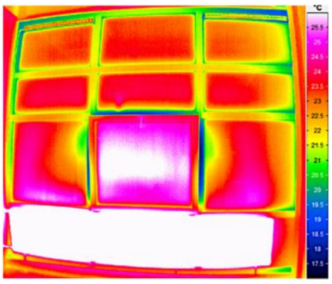


Figure 96: Distorted IR image-Window open

Figure 97: Overlapping-Window open

The Thermal Index has been calculated and the following figure, showing the TI values for each pixel, was generated.

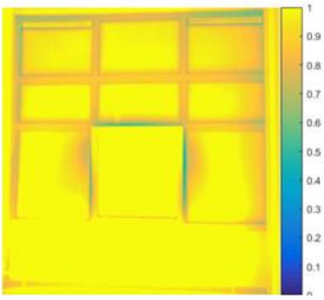


Figure 98: Thermal Index image-Window open

Then, the Thermal Index image has been binarized and overlapped to the visible image of the façade system.

Figure 99: Binarized Thermal Index image-Window open

The figure above reveals evident loss of insulation around the central opened window, as expected. And also on the left and right metal shutter is visible in the upper sides of the figure. This is due to the cooling of the glazing metal frames, which usually have TI low values (indicative of a high U value), but the high U value of the frame averaged with the U value of the entire façade (glazed and opaque portions) does not affect the efficiency of the entire system. The glazing elements show no signs of air leakage.

4.3.2 Use case 2: MEP system – AR on-site simulation

Within the Hogekamp demonstration case in Enschede, all INSITER AR applications have been applied and tested:

- INSITER BIM AR Vision App, demonstrating the visualization of large (in file size) and complex BIM models including referenced planning and measurement data in AR.
- INSITER HoloLens BIM-based Mixed Reality App, demonstrating the detailed BIM model evaluation for self-inspection of the Hogekamp construction environments. See link for short demonstration.
- INSITER BIM-based Self-Instruction AR App, demonstrating / BIM-based process simulations and support for workers on-site, including thermal measurements.

Special focus is on the demonstration of the “INSITER HoloLens BIM-based Mixed Reality App”. This hands-free application enriches the vision of on-site personnel with virtual, interactive BIM objects and information concerning the on-site situation in connection with the BIM model for evaluation, self-inspection and self-instruction.

The demonstration is focused on the evaluation of technical building services such as MEP or HVAC systems on-site, as well as to provide workers with in-situ information about building objects, e.g. which elements have e.g. to be attached, installed or removed. The use of the applications has been proven to be especially helpful for construction and refurbishment works in combination with MEP/HVAC installations, providing works with the instructions and information they need.

Demonstrated main functionalities of the INSITER AR applications

The following main functionalities for the INSITER AR applications have been demonstrated (see also D2.2):

- Identification and visualization of BIM objects and construction elements, object placement, orientation, on-site visual comparison between virtual BIM model and real on-site situation, construction validation and compliance checking (all INSITER AR solutions have been tested and demonstrated).
- Self-instruction and Self-inspection support for on-site construction processes:
  Visual guidance for BIM and MEP concerning installation location. Detailed comparison in Mixed Reality between

virtual BIM model and real on-site situation (INSITER HoloLens BIM-based Mixed Reality App, INSITER BIM-based Self-Instruction AR App)

- Special emphasis for Hogekamp Enschede demonstration case is on BIM model evaluation for self-inspection of detailed 3D construction environments with the evaluation of technical building services and components, such as mechanical, electrical, and plumbing (MEP) or heating, ventilation, and air conditioning (HVAC) systems. (INSITER HoloLens BIM-based Mixed Reality App, INSITER BIM AR Vision App).

Thus, hidden MEP/HVAC elements for building construction and renovation have been revealed in mixed reality for evaluation.

- Access to referenced self-instruction, self-inspection data or planning information on INSITER SharePoint and repository with available guidelines, instrumentation data, visualization of thermal measurements and clash information (clash cubes, clash images) (INSITER BIM AR Vision App , INSITER HoloLens BIM-based Mixed Reality App, INSITER BIM-based Self-Instruction AR App).

Within the following section images of the AR solutions and their on-site demonstration are presented, showing the main aspects of the on-site demonstration as screenshots in addition to the presented illustrations in D2.2.

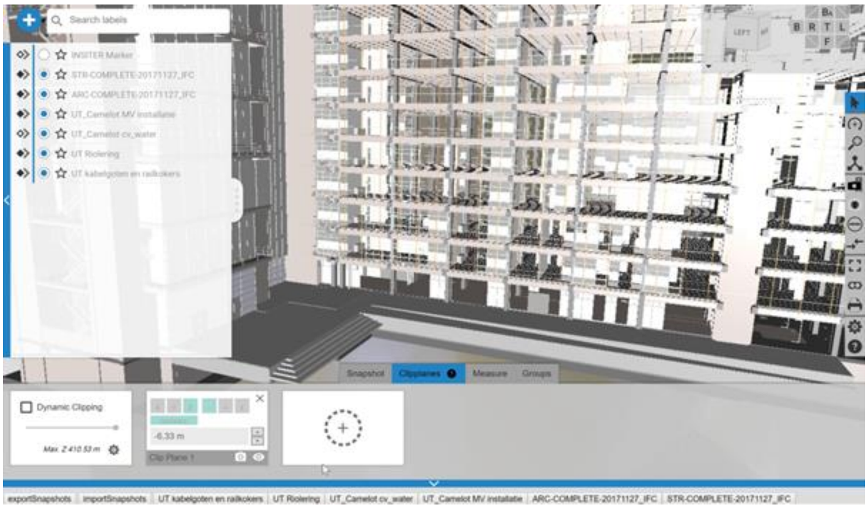


Figure 100: INSITER BIM AR Vision App – On-Site Demonstration with all BIM objects and construction elements (large BIM models)

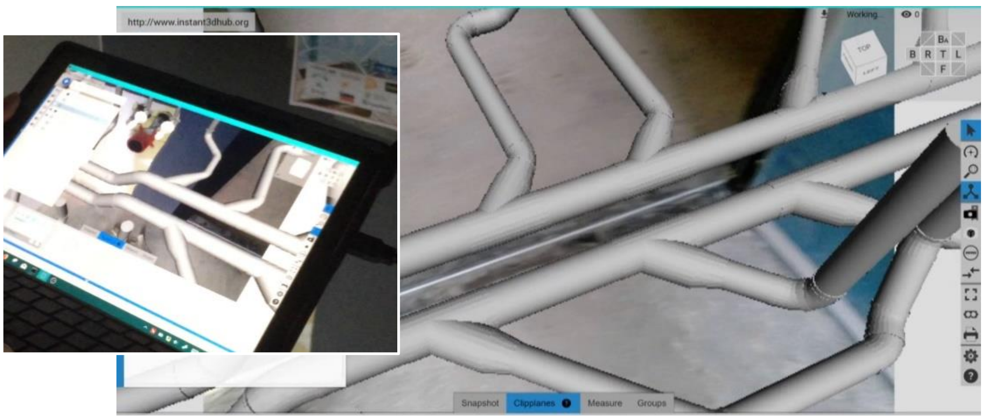


Figure 101: BIM AR Vision App – On-Site Demonstration with focus on MEP or HVAC systems (here: AR visualization of water sewage pipes only), please see also D2.2.

Figure 102: INSITER HoloLens BIM-based Mixed Reality App – On-Site Demonstration with complete BIM model (without ceiling, MEP/HVAC party hidden by digital wall elements)

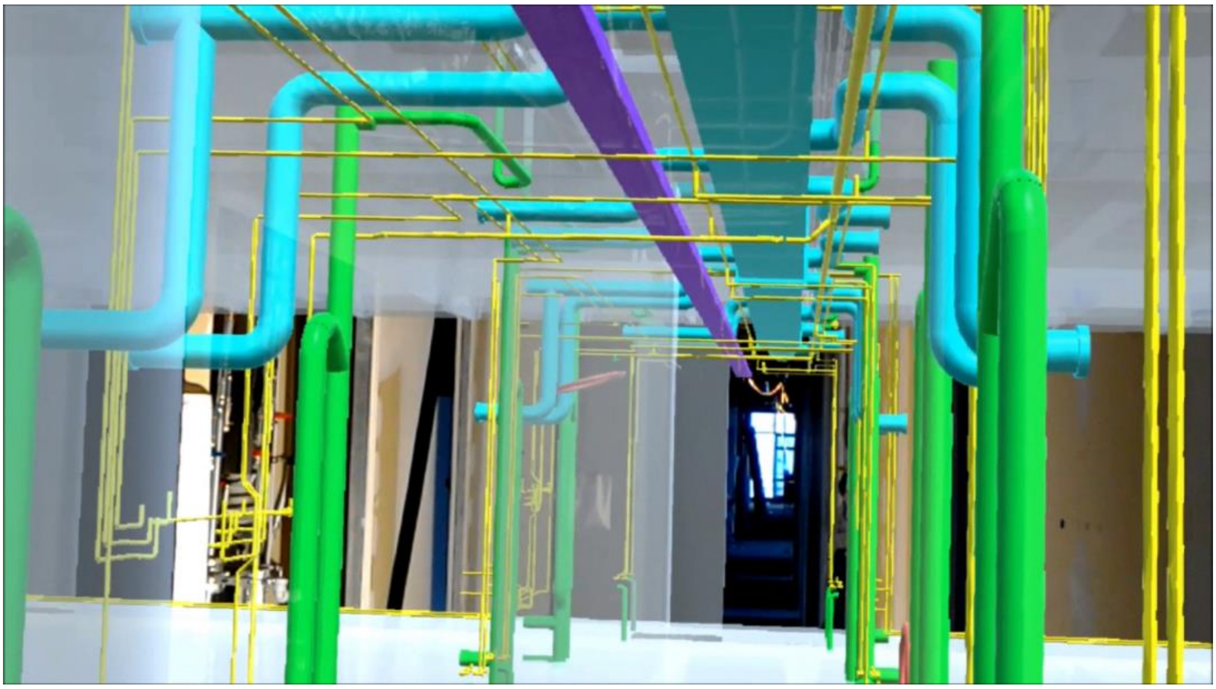


Figure 103: INSITER HoloLens BIM-based Mixed Reality App Screenshots – On-Site Demonstration focus on MEP or HVAC, (without walls and ceiling, structure half transparent, for example).

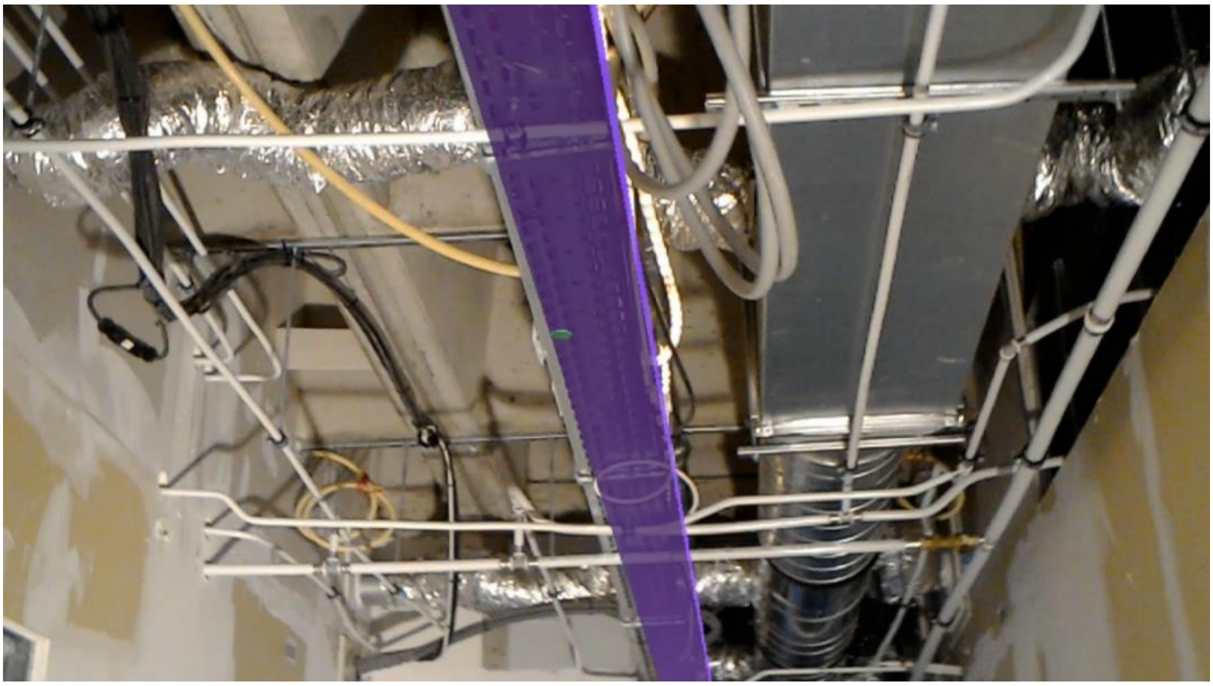


Figure 104: INSITER HoloLens BIM-based Mixed Reality App – On-Site Demonstration focus on MEP with particular visualization of one component for self-instruction or self-inspection (here: cable duct, for example)

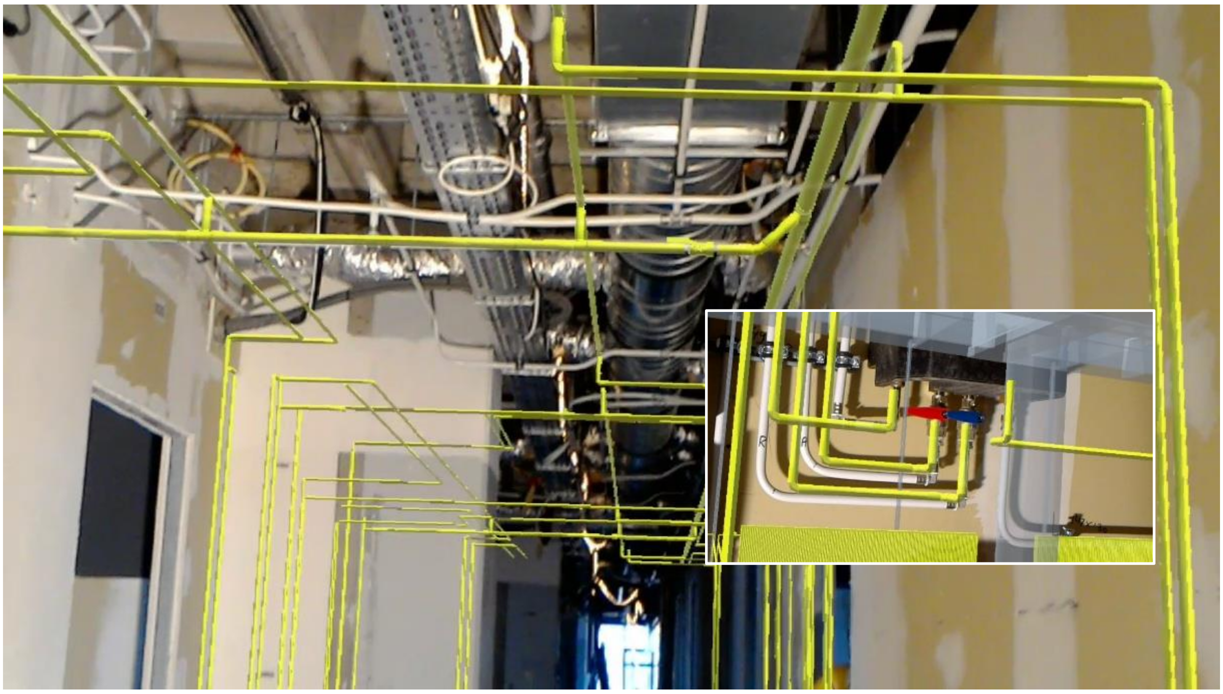


Figure 105: INSITER HoloLens BIM-based Mixed Reality App – On-Site Demonstration focus on MEP with self-instruction and visual guidance, where MEP elements should be installed within the real on-site situation (here: heating system and water supply, for example)

Figure 106: INSITER HoloLens BIM-based Mixed Reality App – On-Site Demonstration focus on MEP with particular visualization of one component (here: waste water system, for example)

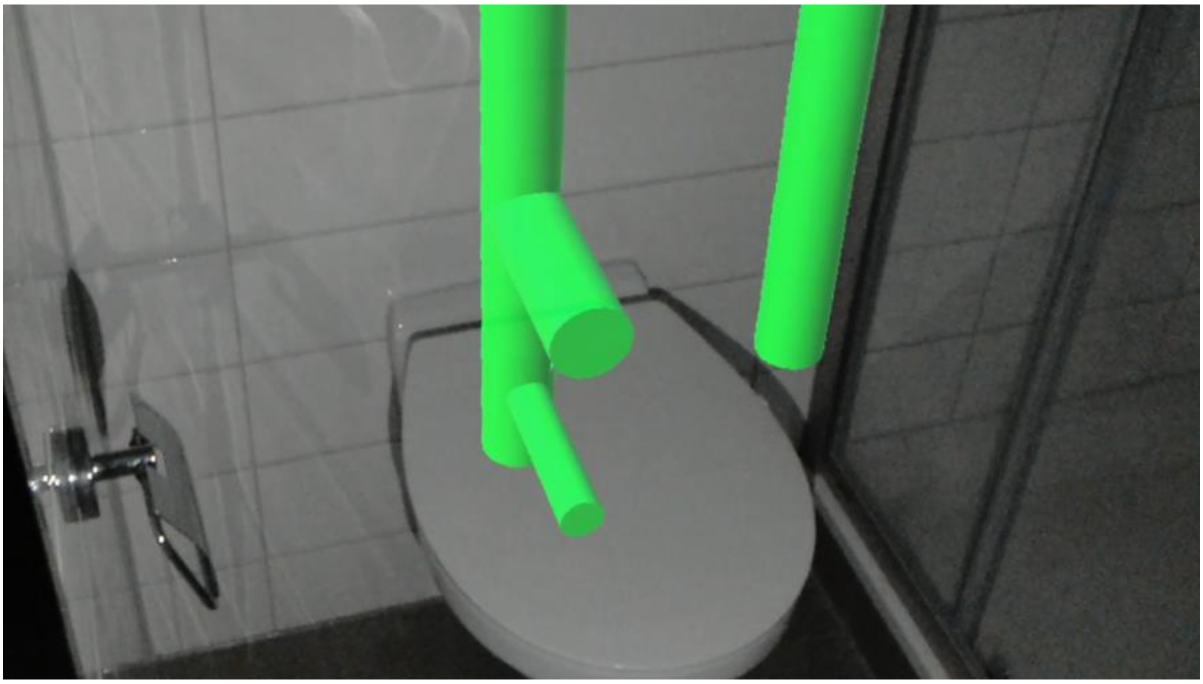


Figure 107: INSITER HoloLens BIM-based Mixed Reality App – On-Site Demonstration focus on MEP with particular visualization of one component (here: waste water system (inside bathroom), for example)

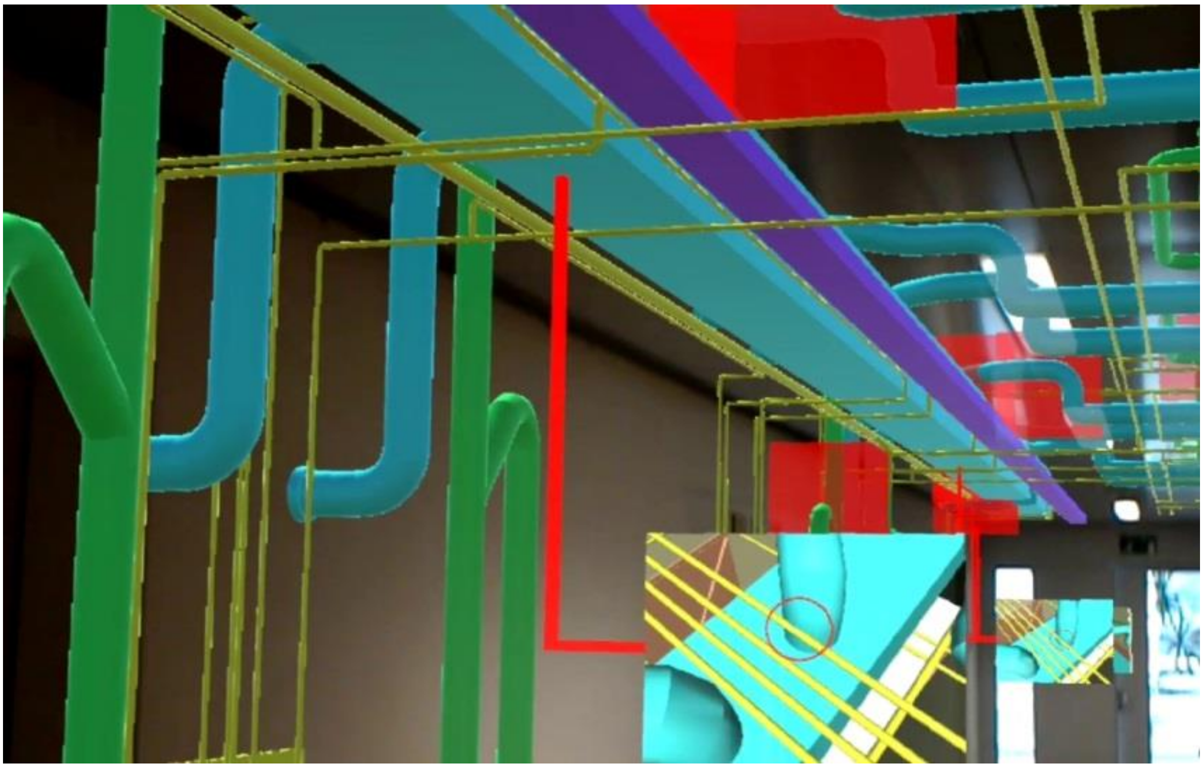


Figure 108: INSITER HoloLens BIM-based Mixed Reality App Screenshot – Evaluation of clash cubes and clash analyses with related clash images

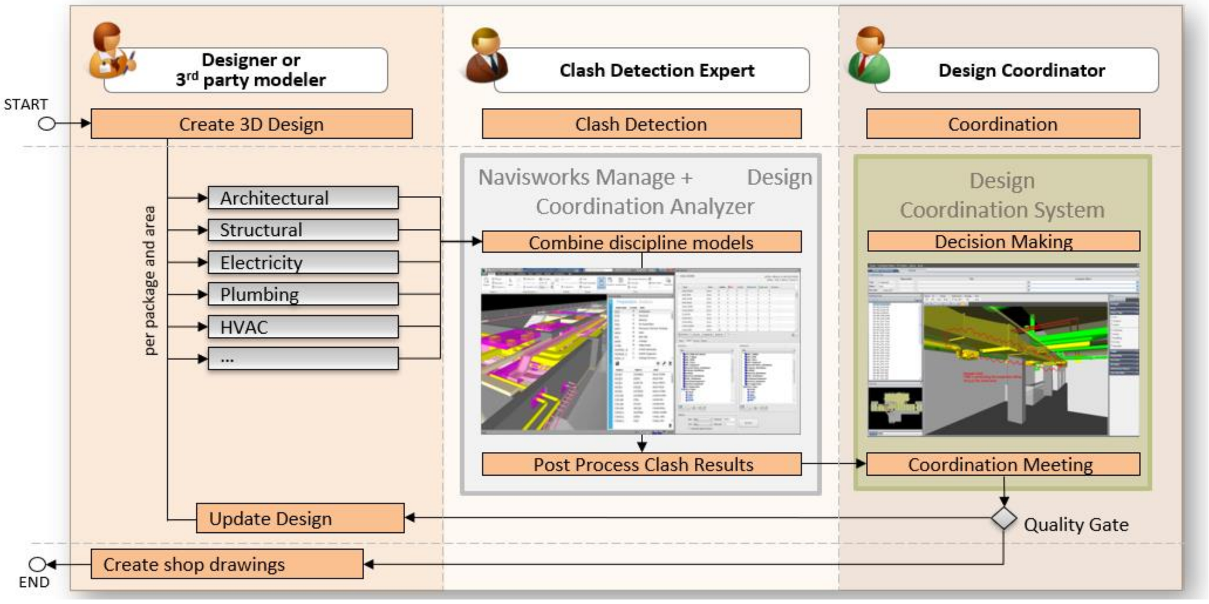


Figure 109: High level Clash Detection process

Before that clash information can be forwarded on site the clash detection process has to be performed. This process is a complete off-site process and has to be done as a prerequisite. The following image shows the whole clash detection process. The tools themselves are explained in deliverable **D4.2 Model Checking, Clash Detection and Value Engineering.**

Before the clash detection process may start, the input data has to be precisely defined and prepared to provide transparency through the whole clash detection process and to enable all involved person to keep track on what exactly has been analysed. One challenge of the clash detection process at the Enschede project was that in the project data has been handed over as a complete project (see picture below). This led to a very difficult clash analysis on one hand (due to the fact that it is hard to position the camera correctly to show a specific conflict) and on the other hand this would have made the clash coordination very difficult (due to the fact that hundreds of conflicts have to be found and coordinated). Because of these reasons the specific part of focus has been cut out of the project model "Handed over project data – complete project".

Using the developed tool "IFC splitter" the project data has been split to enable effective clash detection. The following images show the source code, the user interface and the result of splitting the project data to the focus area. The last preparation step before performing the clash detection was to define what has been evaluated within the clash detection run. Therefore, a Clash Matrix has been set up, which shows:

- Which trades have been evaluated against which other trades,
- Which tolerances have been used for the evaluation,
- Which type of clash detection rule has been used (hard or conservative) and
- Which exceptions have been used (e.g. architecture has not been checked against structure)

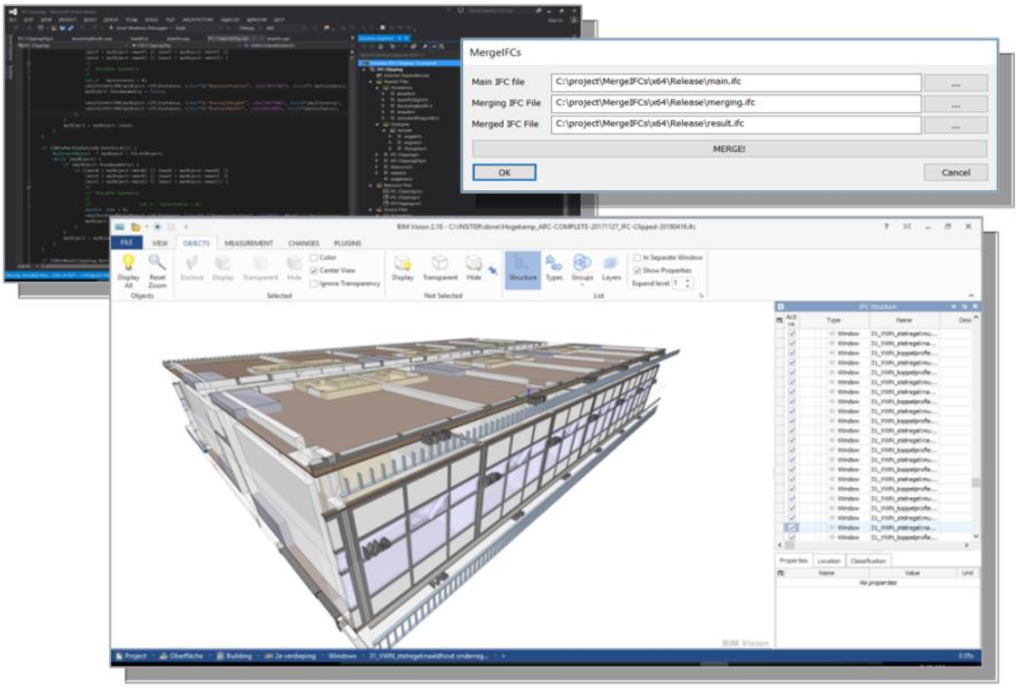
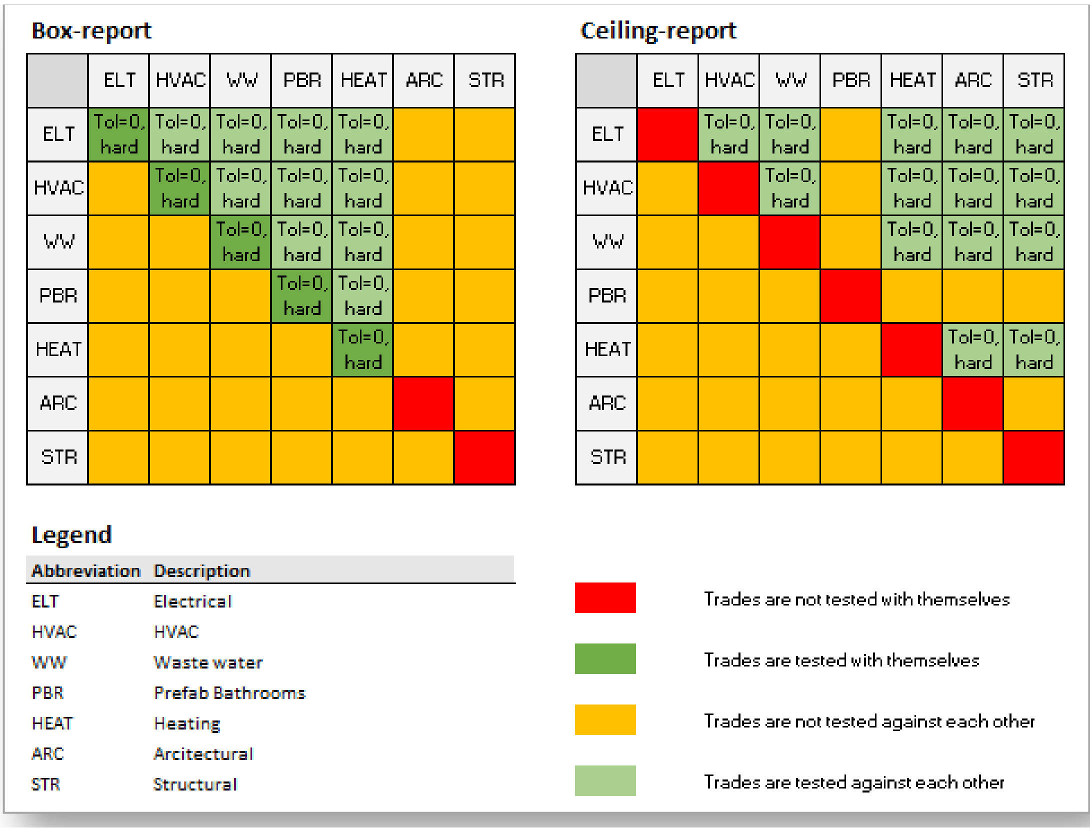


Figure 110: Prepared project data – focus area


Box-report

	ELT	HVAC	WW	PBR	HEAT	ARC	STR
ELT	Tol=0, hard	Tol=0, hard	Tol=0, hard	Tol=0, hard	Tol=0, hard		
HVAC		Tol=0, hard	Tol=0, hard	Tol=0, hard	Tol=0, hard		
WW			Tol=0, hard	Tol=0, hard	Tol=0, hard		
PBR				Tol=0, hard	Tol=0, hard		
HEAT					Tol=0, hard		
ARC							
STR							

Ceiling-report

	ELT	HVAC	WW	PBR	HEAT	ARC	STR
ELT		Tol=0, hard	Tol=0, hard		Tol=0, hard	Tol=0, hard	Tol=0, hard
HVAC			Tol=0, hard		Tol=0, hard	Tol=0, hard	Tol=0, hard
WW					Tol=0, hard	Tol=0, hard	Tol=0, hard
PBR							
HEAT						Tol=0, hard	Tol=0, hard
ARC							
STR							

Legend

Abbreviation	Description
ELT	Electrical
HVAC	HVAC
WW	Waste water
PBR	Prefab Bathrooms
HEAT	Heating
ARC	Arcitectural
STR	Structural

Figure 111: Clash Matrix for the Enschede Project

All that information enabled the Clash Detection Expert to perform the clash detection and forward the results to the Design Coordination System (DCS), where the Design Coordinator and his team coordinated all identified issues and found solutions on how to solve them.

In general, identified issues will lead to another iteration of updating the design as well as the models. But there are also issues, which would lead to too many costs to start another iteration step. Those conflicts, which have to be solved on site, should be forwarded by Clash Cubes. Clash Cubes are small IFC blocks, which include all defined coordination information from the coordination meeting as attributes. These clash cubes can be forwarded and be used to show this information within the Augmented Reality tools.

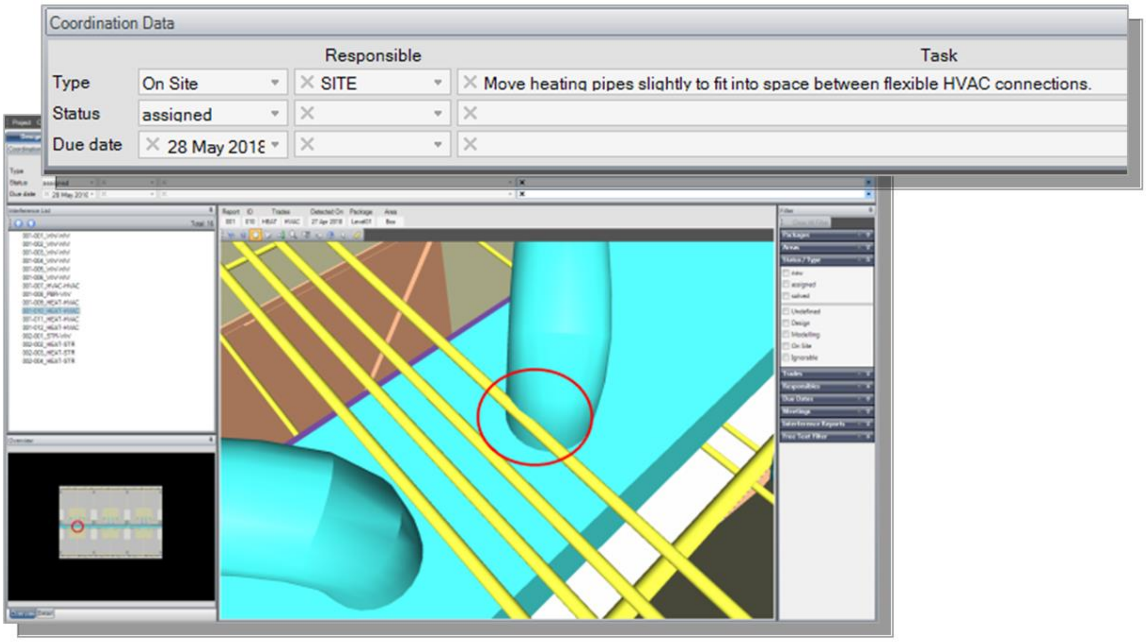


Figure 112: Coordination within the Design Coordination System (DCS)

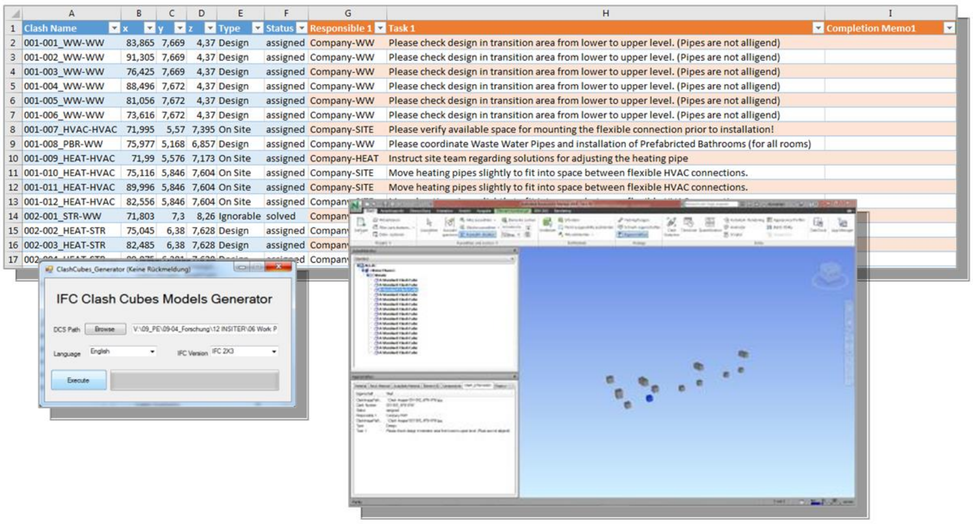


Figure 113: Information from the coordination meeting, Clash Cubes User Interface, Clash Cubes incl. coordination information

The Clash Cubes and the included information have been used to provide the coordination information in the used on-site tools. The following images show their usage in the Augmented Reality model (top left) as well as the usage within the RE Suite (bottom right):

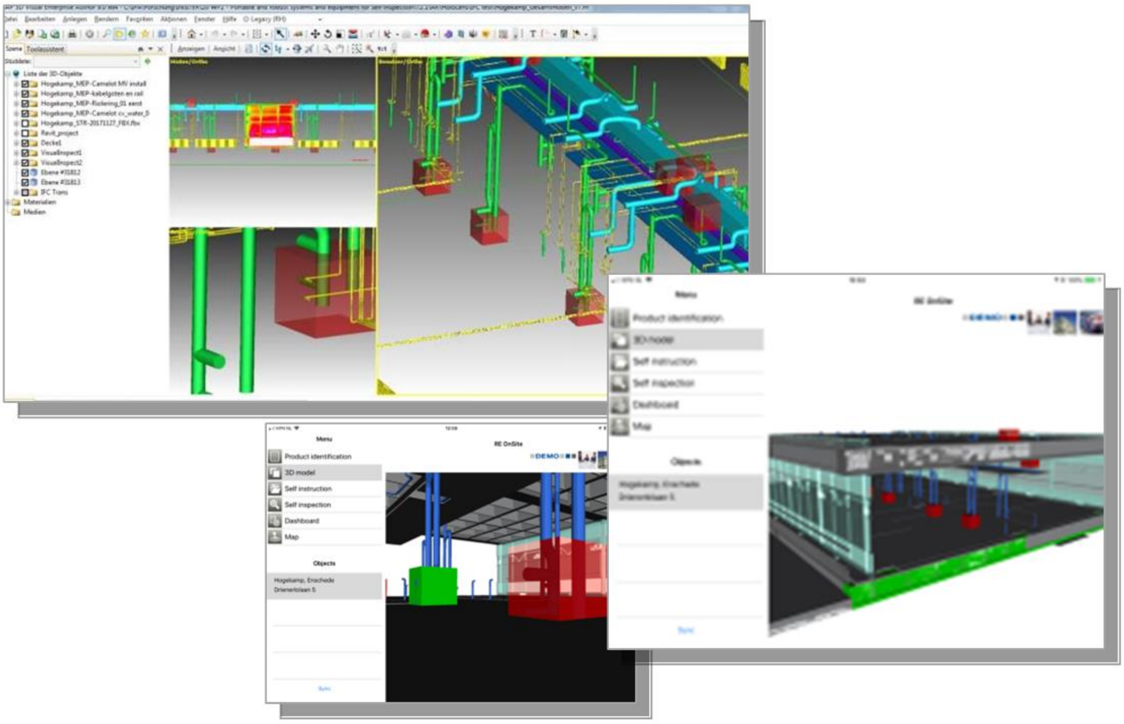


Figure 114: Further usage of Clash Cubes in other tools to be forwarded on site

The developed AR solutions have been presented, demonstrated and also utilized by consortium members, interested stakeholders and also workers on-site. For example, the workers have been supported in the installation validation of building components.

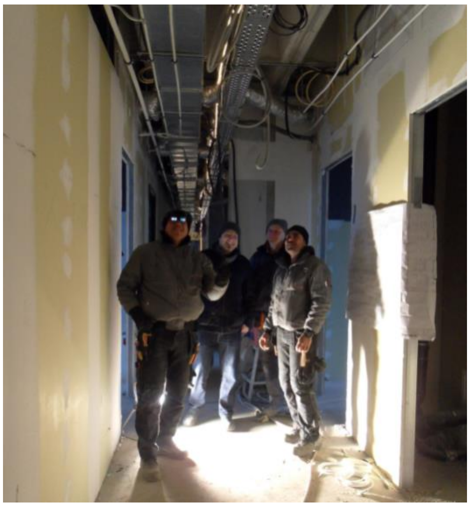


Figure 115: INSITER HoloLens BIM-based Mixed Reality App – On-Site Demonstration with construction workers

During the demonstrations different actors from workers to architects and project managers had the chance to test the AR prototype solutions and give a feedback on the test and demonstration. So far, most of the participants have given a positive feedback and point out the advantages and possibilities of merging digital information with the real on-site situation and work context. As written in D.2.2, any stakeholder can utilize the application for self-inspection or self-instruction. During the construction process workers are supported with visual guidance where to install building elements or identify possible construction errors or clashes on-site. Responsible actors can verify if new construction elements have been mounted correctly or according to the planned schedule. Further possible application scenarios have been demonstrated such as the visualization of available instrumentation and process measurement data e.g. thermal deviations and thermal bridges. The heat dispersion from a heating pipe into the wall was discovered and identified with the combination of measurement data, real building data and the digital BIM model in Augmented or Mixed Reality. Thus, real on-site measurements can be visualised and further analysed by the combination with virtual building information and digital models.

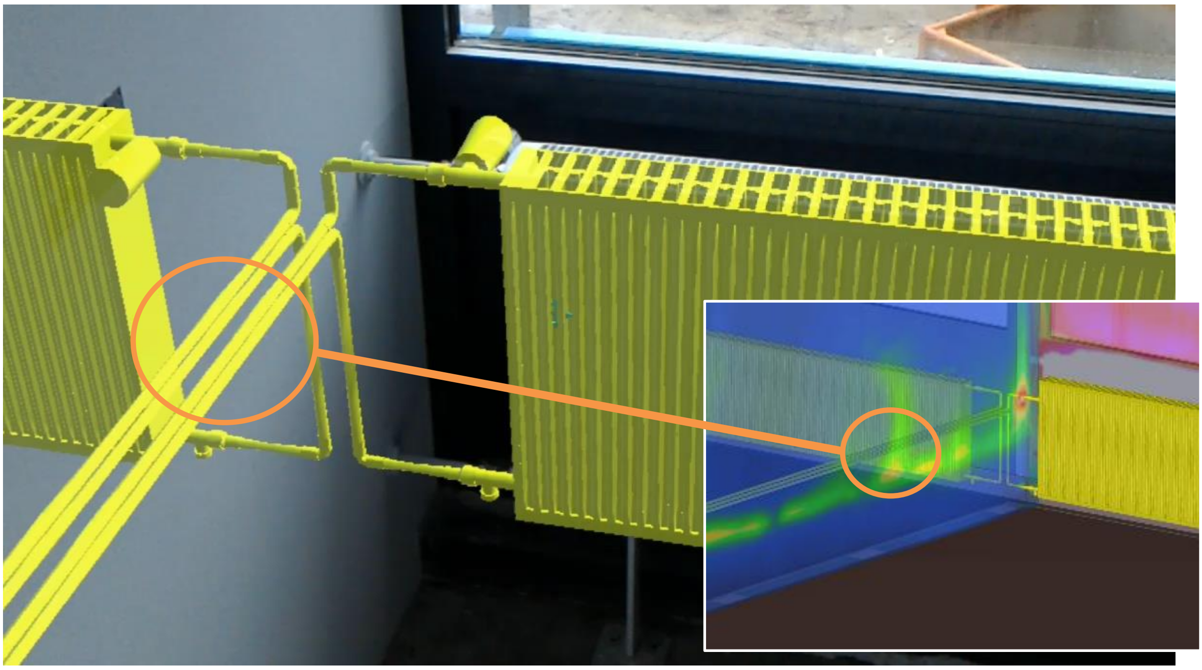


Figure 116: INSITER HoloLens BIM-based Mixed Reality App Screenshots – On-Site Demonstration focus on heating system with visualization of instrumentation measurement data concerning thermal deviations and heat dispersion of heating pipe.

Moreover, the INSITER BIM-based Self-Instruction AR app has been demonstrated to support workers on-site with step-by step self-instruction and detailed BIM-based process simulations, including thermal measurements. Please see also D2.2 for further information on the application.

Figure 117: INSITER BIM-based Self-Instruction AR app visualizing self-instruction information for different BIM objects

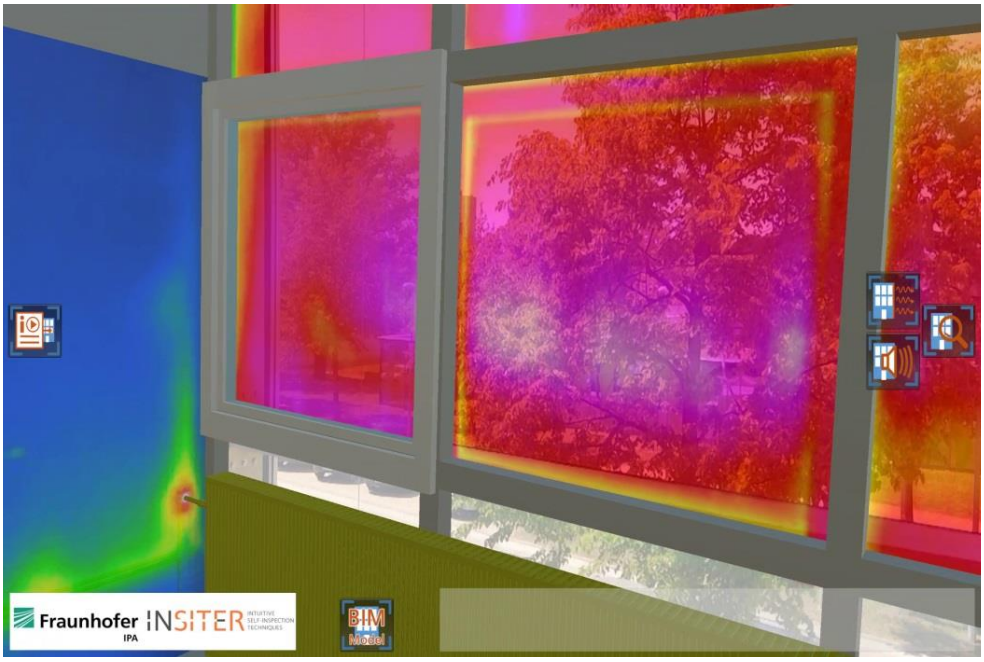


Figure 118: INSITER BIM-based Self-Instruction AR app visualizing thermal measurements images to evaluate thermal deviations and there causes with the help of the digital BIM model and the on-site situation.

Conclusions

Compliance with Key Performance Indicators

The building's thermal performance is one of the Key Performance Indicators to say something about the energy efficiency of the building. If the building envelope presents any irregularities, the building thermal performance and therefore its energy efficiency will be negatively influenced. Those irregularities can be identified by measuring the temperature distribution over the whole building envelope surface which is commonly performed by infrared thermography. A quantitative way to identify thermal irregularities of the envelope is represented by the Thermal Index. The thresholds for the Thermal Index can be found in BRE Information Paper IP 1/06:

- 0,75 for dwellings;
- 0,50 for offices and shops.

If any irregularity is found, corrective measurements have to be taken; not only for thermal reasons, but also for other physical, health and comfort reasons.

Compliance with stakeholder requirements

The goals of Camelot for the Hogekamp building was to improve the energy label from G to B and realize energy efficiency of 60 to 70% compared to the old building before transformation. The main elements to achieve the goals are new façade elements, improved insulation and a new installation. Due to the size of the building and the limited use case, it is not possible to make any reliable statement about the compliance of the use case results and the stakeholder requirements. More and different tests are needed to say something about the expected total building performance. The results of the thermal scanning of the room show no errors or other quality problems which will have a negative effect on the stakeholder requirements.

We have asked (on October 25th 2018) for the actual energy consumption of the Hogekamp building. Until now it is not known and the payment of the energy is based on assumptions and not on real data. Further we have to take into account that the use of energy differs for the activity in the building. This might be different for education purposes compared the housing / hotel purposes.

Improvement and lessons learned

As already concluded in D2.2, new Mixed Reality technologies and developments in the field of construction have the capability to transform our work environment and daily process as well as the use of hardware devices on-site. Nevertheless, further challenges such as national and international regulations concerning the utilization of MR tools on construction sites or within factories as well health and safety issues have to be further elaborated, in order to use these tools without possible distractions and risk of accidents. One approach could be to only focus on dedicated objects not allowing getting too much digital information within the field of view of the user. In this case any actor would still be aware of potential risks on-site. Moreover, the Mixed Reality system could provide warning signals or also fade out the digital representation as soon as any real object or potential hazardous situation is detected nearby using the spatial mapping information of the environment.

The demonstration conducted at the Hogekamp construction site has clearly shown how efficiency and effectiveness can be increased by utilizing the new developed tools and approaches for self-inspection and self-instruction through the visualization of digital objects, planning or process data in combination with a real environment with a direct reference from the real construction environment to digital BIM data.

Furthermore, interactive information for construction processes enables an error-free building construction with the targeted and guided assembly of building elements. The use of augmented reality can prevent construction failures from happening, thus helps to achieve also the best energy efficiency possible by avoiding thermal defects and deviations. The conducted demonstration along with the actors and stakeholders feedback is supporting the further implementation and successful usage of Mixed Reality systems and technologies within real work environments and construction sites. At this point it also has to be mentioned that the demonstrated tools and devices are prototypes. To enable a successful transfer from research towards project usage further developments are required to ease processes and to avoid import- and export procedures of data.

5. Real demonstration case of refurbishment in Pisa, IT

5.1 Changes compared to the original plan described in D5.3

In 2016 the Province of Pisa, after the preliminary phase of inspections and testing, decided to demolish the building and rebuild it, and a public tender for designing the new "Concetto Marchesi" was held in February 2017. The purpose of the tender was to maintain only the fitness building and replace the existing educational facility with a new building, due to the excessive costs imposed by the actual continuous work of maintenance. In June 2017, the design tender has been awarded to AICE, in association with an architectural firm based in Pisa. During the construction works - with the agreement between AICE and the Province of Pisa, owner of the building – AICE will be responsible to perform periodic testing to support the Site manager and the General Contractor. At the moment, the intermediate design phase has been submitted and the approval is expected by the end of 2018. Until the beginning of the works, the entire facility is fully available to organize field testing and inspection for the purpose of the INSITER project, in accordance with the Province of Pisa. Therefore two use cases have been elaborated instead of 3: Geometric consistency check and thermal performance on 2D components are done, checking of connection between existing building and additions using Augmented Reality, is cancelled

5.2 Field validation / demonstration procedures for each use case

5.2.1 Introduction

The school complex, built in mid-1970s as an innovative educational facility, is located in the Eastern side of Pisa, central Italy. The complex has a prefabricated concrete structure with pillars, beams and panels and consists of four different building portions, which house two different high schools, for approximately 14,612 m2 and 43,836 m3, and a total amount of approx. 1,675 students. Those portions are characterized by strongly articulated volumes developed on two, three and four floors above ground. The roof is a broad, slightly sloping surface which was originally a practicable roof for outdoor lessons. The steep pitch of the central core of the building, that hosts the fitness building, stands out for the walkable roof surface. The fitness building, consisting of a swimming pool, two gyms and locker rooms, was added in the 1975 as a detached facility, with an internal hallway that leads directly to the school. At that time, in Italy there were neither seismic nor energetic requirements for new buildings.

Figure 29: construction site of school complex in 1970s showing huge use of prefab components for structures and building envelope

The facility has maintained its occupancy since the construction, and has been subjected to several maintenance works during the past few decades, due to increasingly frequent criticisms, so that in 2015 the Province of Pisa, that owns and manages the building, asked AICE to perform a series of surveys and inspections in order to verify the existing condition of building components. This preliminary mapping phase was aimed at assessing the major building issues and defining refurbishment and/or replacement scenarios.

Since the beginning of the activities, AICE involved the Province of Pisa to receive authorization to use the building as part of the research and demonstration activities of the INSITER project. These inspections were aimed both at highlighting possible safety issues and at detecting construction defects on non-structural elements (windows, roof panels, etc.) that affect the energy performance of the building, in order to plan the total or partial renovation of the building. For the INSITER scope, additional tests and measurements (laser scanning measurements, thermal tests etc.) have been performed on site to work out the use cases as per WP5 actions.

The main problems that emerged from this first phase of investigations consist of:

- Liability of structures and lack of seismic requirements, as currently required in Italy for strategic buildings such as educational, health care facilities etc.
- Poor energy performance of the building envelope (prefab opaque panels, U-glasses of skylights, waterproofing layers), due to bad condition.

During the development of the INSITER project, three different use cases on the building have been proposed:

- Checking of geometric consistency
- Checking of thermal performance on 2D components
- Checking of the connection between existing building and additions using Augmented Reality.

The present deliverable focuses on the assessment of the actual condition and therefore develops and tests use cases 1 and 2. Use cases 1 and 2 can be considered substantially concluded. The latest elaborations and expected results, including KPI measurements and thresholds related to energy efficiency, will be presented in D5.5 as final submission. Therefore the main scope of the demo case, i.e. the mapping of actual condition in order to propose future refurbishment works, is fulfilled.

As regards the proposed third use case, some changes occurred during the development of the project and therefore few deviations from the proposed actions are needed (need confirmation by UNIVPM for the feasibility of additional activities to be performed).

In 2016 the Province of Pisa, after the preliminary phase of inspections and testing, decided to demolish the building and rebuild it and a public tender for designing the new “Concetto Marchesi” was held in February 2017. The purpose of the tender was to maintain only the fitness building and replace the existing educational facility with a new building, due to the excessive costs imposed by the actual continuous work of maintenance.

In June 2017, the design tender has been awarded to AICE, in association with an architectural firm based in Pisa. During the construction works - with the agreement between AICE and the Province of Pisa, owner of the building – AICE will be responsible to perform periodic testing to support the Site manager and the General Contractor. At the moment, the intermediate design phase has been submitted and the approval is expected by the end of 2018. Until the beginning of the works, the entire facility is fully available to organize field testing and inspection for the purpose of the INSITER project, in accordance with the Province of Pisa.

Due to the different timing between design/construction process and the conclusion of INSITER by the end of 2018, the proposed third use case is no longer feasible. However, AICE has proposed to the Province of Pisa to apply the INSITER tools and guidelines during the construction phase, as a support for quality control on site in a real-case situation of the construction market.

5.2.2 Use Case 1: Checking of geometric consistency and BIM validation

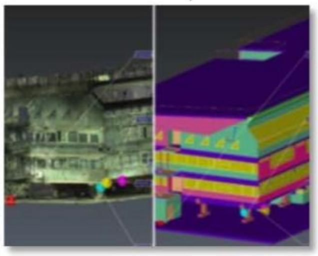
INSITER D5.4; draft template data sheet use case					
Use Case 3.1		**Checking of geometric consistency**			
Relevant Demonstrator		School Complex Pisa			
Responsible Insiter Partner		AICE			
	Description	responsible partner	additional input	time schedule	tools to be used in site testing
Step 1	On site - Laserscan	AICE	3D point clouds	Done - March/April 2016	Leica laserscanner
Step 2	Process 3D point clouds	AICE, HTV	3D point clouds	Done - Nov 2017	n.a.
Step 3	Create the 3D model (meshes)	HTV	BIM model	Done - Nov 2017	Revit
Step 4	Perform alignment	HTV	Comparison point clouds/ 3D-model	Done - March 2017	3DReshaper
Step 5	Perform deviation analysis	HTV	partners on site	Done - April/May 2017	3DReshaper
Step 6	Reports	HTV	partners on site	Done - Nov 2017	n.a.

Table 28: data sheet use case 3.1

The first use case for the school complex in Pisa consists of the check of the geometric consistency by performing a BIM acquisition and a deviation analysis of the model. The development of this use case involves the development and the application of the INSITER methodology, in particular Step 1 – Mapping for existing building and Step 3 – Modelling of the existing building.

The main aim is to assess the quality of as-is building information model generated from point clouds using deviation analysis. The purpose of the project was to map the actual condition of the built-in prefab panels in terms of geometry and energy performance.

The main steps concerning the application of BIM acquisition for Pisa School Complex are:

- Acquire the geometrical data on the building by laser scanning techniques (on site)
- Process 3D point clouds
- Create the 3D model (meshes)
- Perform alignment process between the point cloud and 3D-model
- Perform deviation analysis
- Generate views and provide reports (results on different supports), available on the INSITER SharePoint

The definition of the steps is in accordance with what defined in D5.3 and the validation of the use case has been already completed in November 2017. Some technical results, regarding BIM modelling and deviation analysis, are fully detailed in D4.2 “Model Checking, Clash Detection, and Value Engineering”.

Mapping: Scan to BIM acquisition (On site)

The step has faced the increasing demand of acquire accurate Building Information Models (BIM) of existing building stock with the AEC sector. Therefore this use case can be extended for a general procedure within the INSITER guidelines for mapping actual condition via Scan to BIM techniques.

These as-built BIMs are often required to be modelled up to Level-of-detail (LOD) 300, and up to Level of Accuracy (LOA) 30. To provide this data, high resolution and high accuracy point cloud data is required.

Data acquisition was performed using a terrestrial laser scanner along with total station measurements.

Two major issues in the procedure have been raised:

- Data occlusion: even with high resolution survey data, occluded zones like the interior of walls, floors and ceilings, cannot be avoided. However, a lot of occlusion is caused by the sensors position. Scan to BIM algorithms are forced to make assumptions about these zones, which often lead to misinterpretation. To minimize data occlusion, data coverage should be maximized, and thus, the sensor should be able to access all kinds of spaces;
- Resolution of the survey data: different zones and objects require a certain data resolution in order to be modelled correctly. However, with data resolution inversely proportional to the acquisition speed, the resolution/acquisition time ratio has to be optimized. Acquisition workflows should aim for maximizing speed with a minimum of misinterpretation.

Also the type of point cloud influences Scan to BIM efficiency. Different survey systems provide varying types of point clouds. Reconstruction algorithms preferably work with structured data, for computational efficiency.

Terrestrial laser scanner has been selected for this use case. Over the last decades, acquisition times have dropped from over half an hour to only a couple of minutes for each scan. This allows for more setups, resulting in larger data coverage. With data acquisition speeds up to a 1,000,000 HZ, weight down to 5-10kg, increased accuracies to up to 6mm/100m, terrestrial laser scanners look stronger than ever. The technical data of the laser scanner Leica ScanStation C10, that has been used in the field activities, are the following:

Instrument type: Compact, pulsed, dual-axis compensated, high speed laser scanner, with survey-grade accuracy, range, and field-of-view; integrated camera and laser plummet

User interface: On-board control, notebook, tablet PC or remote controller

Data storage: Integrated solid-state drive (SSD), external PC or external USB device

Camera: Auto-adjusting, integrated high-resolution digital camera with zoom video

Accuracy of single measurement	
Position:	6 mm
Distance:	4 mm
Angle (horizontal/vertical):	60 µrad / 60 µrad (12" / 12")
Modeled surface precision/noise	2 mm
Target acquisition	2 mm std. deviation
Dual-axis compensator	Selectable on/off, resolution 1", dynamic range +/- 5', accuracy 1.5"
Range:	300 m @ 90%; 134 m @ 18% albedo (minimum range 0.1 m)
Scan rate:	Up to 50,000 points/sec, maximum instantaneous rate

Scan resolution	
Spot size:	From 0 – 50 m: 4.5 mm (FWHH-based)
	7 mm (Gaussian-based)
Point spacing:	Fully selectable horizontal and vertical; <1 mm minimum spacing, through full range; single point dwell capacity.

Scanning speed can be increased even more using Multiple-Pulses-in-Air (MPiA) technology in pulse-based Time of Flight (TOF) laser scanners. Also, the implementation of full waveform analysis has led to more accurate data, effectively removing mixed edge pixels and capturing multiple returns from the laser beam. Furthermore the capability to capture RGB data along with LIDAR data is an important asset. While RDB and LIDAR acquisition are currently separated, simultaneous acquisition of RGB and LIDAR is an on-going research but not very affordable for everyday use.

Terrestrial laser scanning is a multidisciplinary employed system for scanning operations. With its simple tripod setup, the tool can enter any area inside and outside of buildings, and provide high accurate, high resolution point cloud data at increased ranges. For now, terrestrial laser scanners are the only devices capable of providing a standalone solution for the capturing of Architectural, Engineering and Construction projects.

Some innovative and time-saving procedures have been introduced in the self-instructions:

- Eliminating scanner setup, tear-down and powering off/on between stations saved five minutes per setup, resulting in a time reduction of 36 %. With more than 400 setups, the net savings were significant;
- Using a wireless tablet with a larger display to control scanning, photo capture, and target acquisition provided high visibility for scan quality monitoring and better zooming resolution for critical aiming at targets. In addition, operators were free to roam while scanning and were able to record targets with the tablet while walking to the next location.

Figure 120: Laserscanner Leica ScanStation and portable device

Perform alignment and deviation analysis

The deviation analysis has been performed using the 3DReshaper software and it represents the core activity of use case 1. The deviation analysis process for detecting modelling errors involves several steps.

First, the as-is BIM data and the point data should be aligned, since they had different locations. Ideally, the entire BIM could be compared with the point data in a single operation, but existing software is not capable of handling the large data sets that would be involved and also cannot easily visualize deviations in building interiors. To address these limitations, we segment a facility into smaller surfaces, such walls, floors, and ceilings of individual rooms, and then conduct deviation analysis separately on each surface. The data for each surface is first segmented from the as-is BIM and the point cloud data.

Then, deviations are computed between the segmented BIM data and the point cloud data. Next, the deviations are visualized in the form of a deviation map. The deviation maps are then analysed to determine the cause of each significant deviation. Finally, the results are summarized and combined with the analyses of other surfaces.

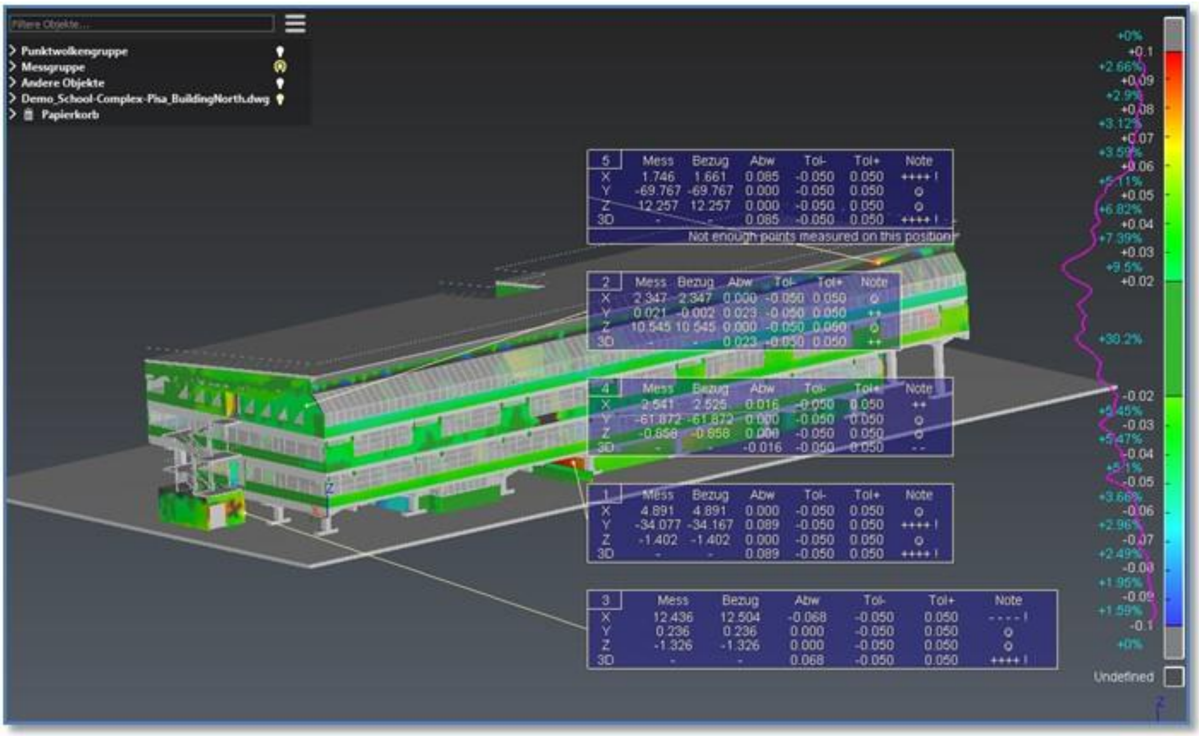


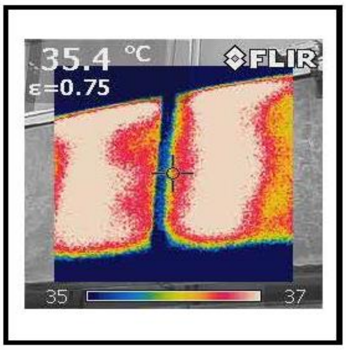
Figure 121: Deviation analysis – Deviation information of specific points

5.2.3 Use Case 2: Checking of thermal performance on 2D components

INSITER D5.4; draft template data sheet use case

Use Case 3.2

Checking of thermal performance on 2D components



Relevant Demonstrator: School Complex Pisa
Responsible Insiter Partner: AICE

	Description	responsible partner	additional input	time schedule	tools to be used in site testing
Step 1	On site	AICE	Thermal images	March/April 2018	FLIR B60 IR camera
Step 2	Calculation of U values	AICE	n.a.	March/April 2018	n.a.
Step 3	Perform thermal scanning to identify thermal bridges	UNIVPM	AICE	June/Sept 2018	IR camera
Step 4	Calculate thermal bridge incidence factor	AICE, supported by UNIVPM	2D temperature map	June/Sept 2018	INSITER procedures
Step 5	Calculate the real thermal transmittance	AICE, supported by UNIVPM	U values	June/Sept 2018	INSITER procedures
Step 6	Integration on the INSITER software	AICE, supported by DEMO	Real U values and thermal bridges impact	Sept/Oct 2018	INSITER tool
Step 7	Reports	AICE, supported by DEMO	Identify inconsistencies in terms of code compliance	Sept/Oct 2018	INSITER tool

Table 29: data sheet use case 3.2

The present use case for the existing School Complex involves the assessment of 2D facade panels, to verify the thermal performance of the envelope and identify the presence of thermal bridges that have been detected using infrared camera. Therefore, the use case is a development of Step 1 – Mapping of the INSITER methodology and can support in the self-inspection phases, such as diagnostic and building assessment, pre-construction, post-construction, and maintenance.

A first analysis has been carried out by “traditional” inspection techniques in April 2016. This analysis has provided only “qualitative” information about the thermal bridge asset. In order to evaluate the thermal bridge impact on the building performance, the following steps have been followed:

- Analyzing plans, sections, details, shop-drawings, as-builts and technical documentation (if available) in which the geometric and technological characteristics of the building are reported;
- Visual inspection in situ in order to detect visible areas of mold on the building envelope;
- Use of the infrared camera to detect the most discrete discontinuities at sight. The thermal image is visible, even to unskilled personnel, as well as the heat flow and thermal dispersions associated as pillars in wall, beams, etc.

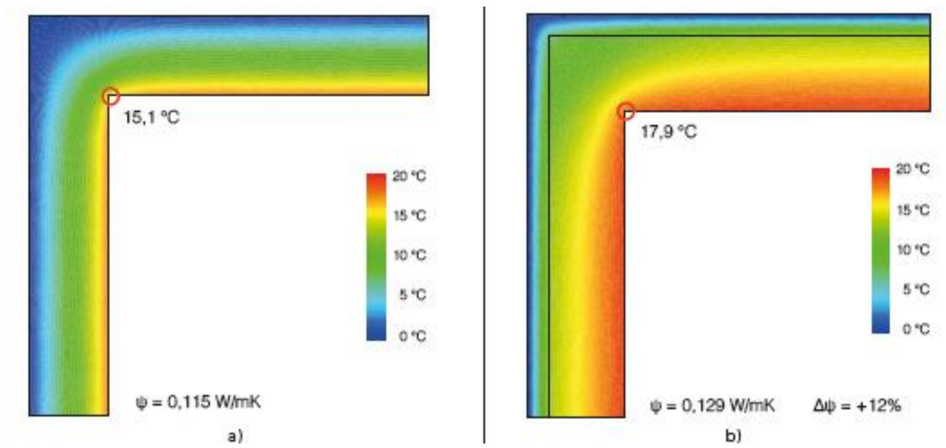


Figure 122: a) Thermal corner bridge between two uninsulated vertical walls. b) Angular thermal bridge between two exterior walled vertical walls (modified solution). Simulation performed with the TerMus-PT version 6.00a software.

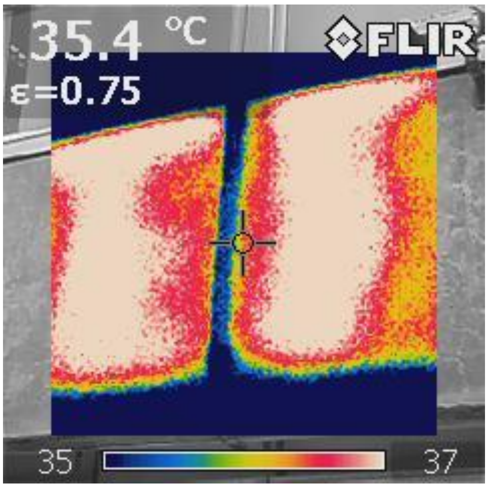
As already mentioned in D5.3, the inspections and surveys have been performed by a FLIR B60 camera, capable of capturing the energy emitted by hot bodies (-20 ° C <T <120 ° C) in the form of electromagnetic radiation of the band "infrared" / LW (long wave) and turn it into thermographic image. The analysis has been conducted in the passive voice, i.e. using the direct solar radiation incident on surfaces and natural convective flows.

These are the main tech features of the camera:

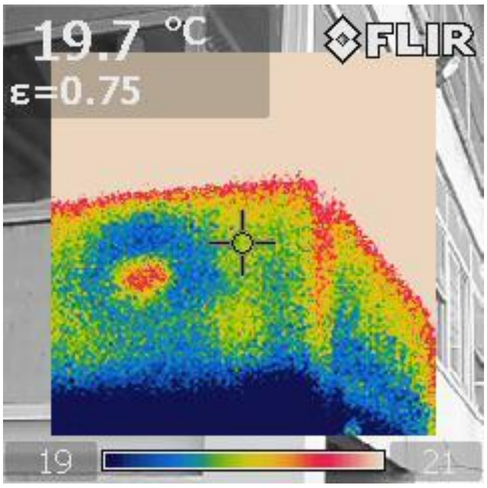
Temperature range:	-20°C to 120°C)
Temperature accuracy:	±2°C or ±2% of reading
Image Storage:	(1GB micro SD card) 1000 Images
Emissivity Table:	0.1 to 1.0 (adjustable)
Field of view/min focus distance:	25° X 25°/0.10m (3.9")
Thermal sensitivity (N.E.T.D):	<0.08°C at 25°C
Spectral range:	7.5 to 13µm
Detector Type - Focal plane array:	32,400 pixels (180 x 180)
(FPA) uncooled microbolometer	

Some hypotheses have been made to perform calculation and assess the thermal behaviour of the envelope, both in terms of thermal transmittance and in thermal bridges. The analyses have been focused on four opaque components:

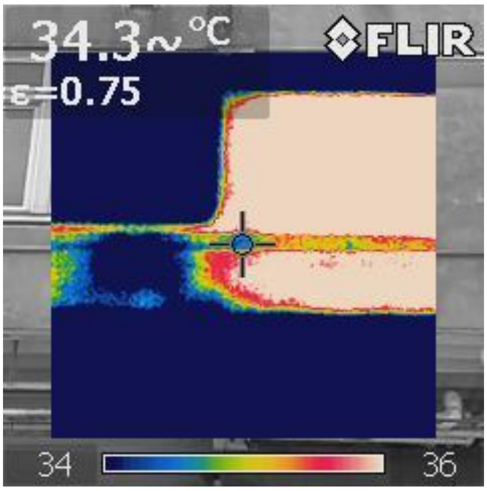
1. Connection between two adjacent opaque panels
2. Corner connection between two opaque panels
3. Presence of reinforced concrete slab (discontinuity)
4. Connection between two adjacent opaque panels



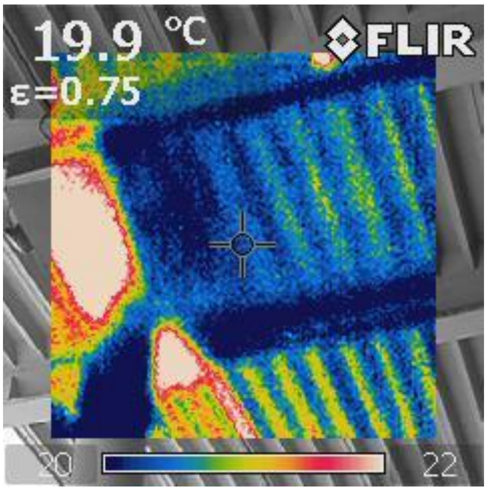
1.



2.



3.



4.

The future development of the use case involves the validation on site of the protocols described in D5.1-D5.2 for lab tests. These protocols will be adopted on site in the School Complex, in order to validate the test case 1 regarding the thermal performances of the building envelope.

Thus, as demonstrated in D2.3, the thermal bridge incidence factor can be assessed by estimating the geometrical extension of the thermal bridge with respect to the sound area via a 2D temperature map of the building component. This thermal image can be provided by an IR camera. The real thermal transmittance in presence of thermal bridge can be calculated once known the thermal transmittance of a sound area (unaffected from thermal bridge). Considering the reference transmittance, calculated by AICE, 1.2W/m²K, it will be feasible to calculate the real thermal transmittance.
The use case aims at validating on site the self-instruction procedures to evaluate thermal bridges. The self-inspection procedures to perform thermal bridge checks (according to the guidelines described in D5.1, Section 3.2 and D5.2, Section 2.1.2) will be defined specifically for this use case, outlining some constraints such as:

- type and location of the room to be tested, based on the envelope features (presence of prefab panels, windows, etc.).
- arrangement and geometry of the measurements tools, for example the position of the camera in relation to the established field of view (FOV).
- type of system to create a thermal gradient.
- definition of thermal bridges acceptability.

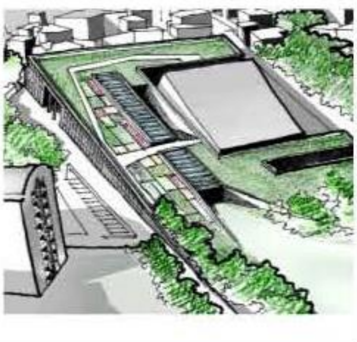
In addition, those energy related parameters will be integrated and sent to the INSITER software to calculate building energy performance and verify the compliance with applicable standards.

The results from use case 2 will be combined with the outcomes of use case 3, related to AR application. Therefore, it is scheduled to perform the use case following the time schedule above in the data sheet above.

5.2.4 Use Case 3: Checking of the connection between existing building and additions using AR

INSITER D5.4; draft template data sheet use case

Use Case 3.3 — **Checking of the connection between existing building and additions using Augmented Reality**



Relevant Demonstrator: School Complex Pisa
Responsible Insiter Partner: AICE

	Description	responsible partner	additional input	time schedule	tools to be used in site testing
Step 1	Preparation and retrieval of latest IFC BIM model	AICE and HVC	-	June/July 2018	IFC viewer, INSITER AR
Step 2	Conduct thermal measurements, configuration of AR system	AICE, UNIVPM, FhG	partners on site	September/October 2018	INSITER measurement tools, INSITER AR
Step 3	Application of AR to identify quality problems (thermal bridges) and construction inconsistencies on-site	AICE, FhG	partners on site	September/October 2018	INSITER AR
Step 4	Application of AR to evaluate new building elements and joints	AICE, FhG	partners on site	September/October 2018	INSITER AR
Step 5	Visualization of referenced measurement data	AICE, FhG	partners on site	September/October 2018	INSITER AR

Table 30: data sheet use case 3.3

As anticipated in D5.3, the School Complex will be repaired by replacement and only the pool building will remain in place. AICE is actually responsible for the design and the definition of the technical specifications, in which the application of INSITER procedures will be included. Thus, AICE will be responsible for checking and verifying site activities during construction, on the behalf of the public owner, the Province of Pisa.

The new School Complex (highlighted in yellow) will have a four storey building that will “surround” the gym/pool building (in light blue). The interface (in red) is represented by the lockers room and the staircase that will connect the school with the fitness centre. The relation between new and existing buildings is crucial in the proper realization of the building, especially in terms of safety works for local demolition and subsequent installation of new building components, in order to avoid thermal bridges and differences in energy performance between the existing elements and the new components to be installed.

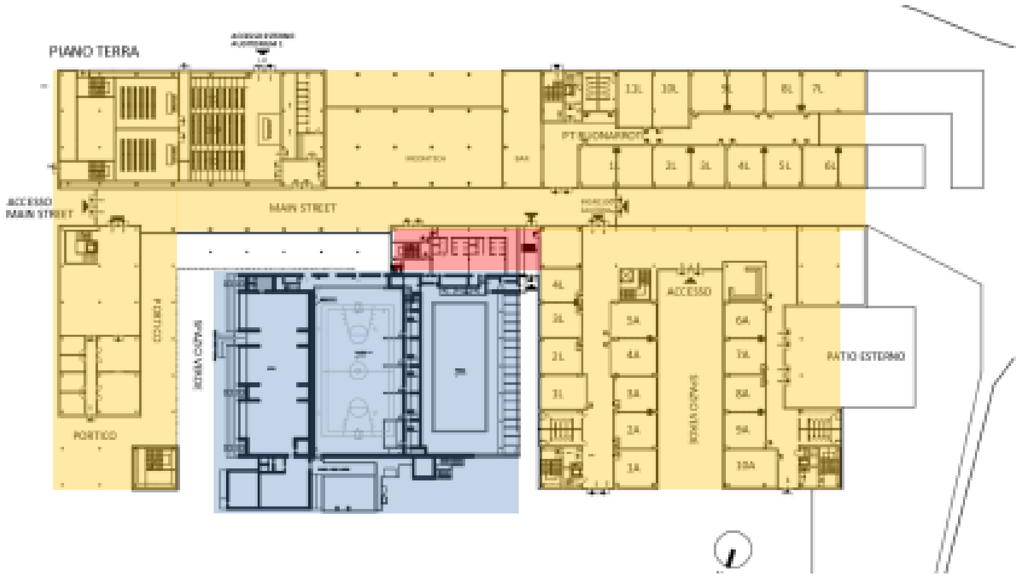


Figure 123: Design condition - General plan of the new educational facility and the remaining gym building

Therefore, also due to time constraints between the INSITER development and the real construction of the building, one of the most important issues where the INSITER AR can be applied is the connection between the existing facility and new building. This use case will develop the INSITER Step 4 – Generating and deploying BIM-based augmented reality for self-instruction and self-inspection.

The main steps concerning the application of AR for the school complex in Pisa are:

- BIM-based evaluation of new built-in elements and installed components concerning the connection of components and thermal measurement data.
- Identify quality problems and construction inconsistencies
- Verification of the building connection and placement of BIM elements of the new part of the building.
- Visualization of referenced measurement data

It is scheduled to perform evaluations during the use case according to the data sheet above.

During the pre-construction phase, workers/inspectors will utilize augmented reality on-site concerning the joints of the existing gym/pool and new building, to identify quality problems (thermal bridges) and construction inconsistencies on-site. Thus, the INSITER AR toolset will provide self-inspection functionalities during the construction phase. The time schedule for this use case may vary due to the design progression. The first stage of design will be completed by December 2017; the request for approval to the Authorities will be set in February 2018, while the final design will be submitted in May 2018. The construction will likely start next September 2018, but the schedule may vary depending on public tender procedures. For this reason, a time schedule is estimated accordingly.

TESTINGS OVERVIEW SCHOOL COMPLEX, PISA

Use case	M36 Nov 17	M37 Dec 17	M38 Jan 18	M39 Feb 18	M40 Mar 18	M41 Apr 18	M42 May 18	M43 Jun 18	M44 Jul 18	M45 Aug18	M46 Sept18	M46 Oct 18
Use case 3.1: Checking of geometric consistency and BIM validation	Deviati on analysis											
Use case 3.2: Checking of thermal performance on 2D components								Definition of test conditions and parameters. On site thermal measurements				Reports
Use case 3.3: Checking of connection between existing building and additions using Augmented Reality								Preparation and retrieval of latest IFC BIM model		On site AR application		Reports

Table 31: Overview testing activities

5.3 Real measurement values / demonstration results from each use case

5.3.1 Introduction, objectives, purpose of the demo and target group

Three use cases had been initially defined to be validated in the existing school complex “Concetto Marchesi”, focusing on the assessment of the building envelope. The third use case, “checking of the connection between existing building and additions using INSITER guidelines and AR technology”, cannot be performed due to the change of decision of the building owner who opted to replace the facility instead of propose a complete refurbishment. The other two use cases mentioned before are related to the methodologies and technologies developed within the INSITER project to evaluate the geometric features and thermal performance of the building envelope. Those measurements, tests and BIM-based simulations, along with suitable KPIs and related conclusions, are reported in this chapter.
In order to carry out these activities, AICE worked together with HOCHTIEF and UNIVPM.

Purpose of the demo and target group

The purpose of the project was to map the actual condition of the built-in prefab panels in terms of geometry and energy performance, using a combination of standard procedures and INSITER methodologies and protocols.

Description of the demonstration building

The demonstration case of School Complex “Concetto Marchesi”, located in the eastern portion of Pisa, is an educational facility built in the 1970s with a modular construction system. The complex has a prefabricated concrete structure with pillars, beams and panels and consists of four different building portions, which house two different high schools, for approximately 14,612 m2 and 43,836 m3, and a total amount of approx. 1,675 students. Those portions are characterized by strongly articulated volumes developed on two, three and four floors above ground. The roof is a broad, slightly sloping surface which was originally a practicable roof for outdoor lessons. The steep pitch of the central core of the building, that hosts the fitness building, stands out for the walkable roof surface. The fitness building, consisting of a swimming pool, two gyms and locker rooms, was added in the 1975 as a detached facility, with an internal hallway that leads directly to the school. At that time, in Italy there were neither seismic nor energetic requirements for new buildings. The facility has maintained its occupancy since the construction, and has been subjected to several maintenance works during the past few decades, due to increasingly frequent criticisms, so that in 2015 the Province of Pisa, that owns and manages the building, asked AICE to perform a series of surveys and inspections in order to verify the existing condition of building components. This preliminary mapping phase was aimed at assessing the major building issues and defining refurbishment and/or replacement scenarios.

Since the beginning of the activities, AICE involved the Province of Pisa to receive authorization to use the building as part of the research and demonstration activities of the INSITER project. These inspections were aimed both at highlighting possible safety issues and at detecting construction defects on non-structural elements (windows, roof panels, etc.) that affect the energy performance of the building, in order to plan the total or partial renovation of the building.

If AICE, as SME and architectural/engineering service company, had faced this mapping and inspection phase using a traditional approach, it would have been necessary to employ 2 or more teams on site to carry out surveys. This would have led to inspections for about 2-3 weeks, considering the extension and volume of the building, and would have required a subsequent phase for graphic restitution and evaluation in the office.
For the INSITER objectives, additional tests and measurements (laser scanning measurements, thermal tests etc.) have been performed on site to work out the use cases as per WP5 actions.

The activity of AICE was precisely that of tackling this project assignment using the methodology and measurement techniques proposed by INSITER, with the aim of demonstrating how the INSITER methodologies allow accelerating on-site times and providing more reliable results for building assessment.

Figure 124: Pictures of the construction site of the School Complex in 1970s, showing the huge use of prefab components both for the structures and the building envelope. Below, the School Complex after completion.

Figure 125: The School Complex after completion

From a structural point of view, it should be also underlined that this facility has been originally designed in the '70s to resist against vertical loads only, since seismic requirements were not present at that time. Nowadays, Italian applicable standards, in accordance with Eurocode indication, require to perform a seismic vulnerability assessment for existing buildings classified as "strategic" such as educational, health care facilities, etc. Based on the results of this analysis, the building must undergo seismic retrofit interventions to comply with current structural requirements. This aspect is not detailed here and reported because it is outside the scope of INSITER, but it is the essential element for the reuse of the building as an educational facility, in terms of safety for the users.

The two main problems that needed to be assessed throughout surveys and the investigations consist of:

- Poor safety performance of the building envelope elements. In particular, liability of non-structural elements (prefab panels), that could collapse and cause injuries to the building occupants.
- Poor energy performance of the building envelope (prefab opaque panels, U-glasses of skylights, waterproofing layers), due to bad condition.

During the development of the INSITER project, three different use cases on the building have been initially proposed:

- Building envelope – Checking of geometric consistency (mapping and BIM deviation analysis)
- Building envelope – Checking of thermal performance on 2D components (self-inspection at building component level)

- Checking of the connection between existing building and additions using Augmented Reality.

The present deliverable focuses on the assessment of the actual condition and therefore develops and tests use cases 1 and 2. Use cases 1 and 2 can be considered substantially concluded.

Therefore the main scope of the demo case, i.e. the mapping of actual condition in order to propose future refurbishment works, is fulfilled.

As regards the proposed third use case, some changes occurred during the development of the project and therefore few deviations from the proposed actions occured, as outlined to the Project Coordinator (letter dated 6th July 2018). In 2016 the Province of Pisa, after the preliminary phase of inspections and testing, decided to demolish the building and rebuild it, and a public tender for designing the new “Concetto Marchesi” was held in February 2017. The purpose of the tender was to maintain only the fitness building and replace the existing educational facility with a new building, due to the excessive costs imposed by the actual continuous work of maintenance.

In June 2017, the design tender has been awarded to AICE, in association with an architectural firm based in Pisa. During the construction works - with the agreement between AICE and the Province of Pisa, owner of the building – AICE will be responsible to perform periodic testing to support the Site manager and the General Contractor. At the moment, the intermediate design phase has been submitted and the approval is expected by the end of 2018.

Due to the different timing between design/construction process and the conclusion of INSITER by the end of 2018, the proposed third use case is no longer feasible. However, AICE has proposed to the Province of Pisa to apply the INSITER tools and guidelines during the construction phase, as a support for quality control on site in a real-case situation of the construction market.

Contribution of partners

The contribution of the partners and their role in the two use cases of Pisa demo case are described in paragraphs below. The involved partners representing different SIG´s and stakeholders are:

- AICE Consulting, building inspectors, design partner, and on-site building experts to perform 3D laser scan and thermal measurements with infrared camera.
- Province of Pisa, client, owner and building manager
- HVC, BIM modelling, deviation analysis on base of laser scan performed by AICE, creation of TruViews from laser scans
- UNIVPM, Conclusion on thermal measurements

Stakeholders involved: Client, designers, architects, engineers, and inspectors.

Description of set of demonstrations

Two main use-cases have been defined for the Pisa demonstration case:

1. Building envelope – Checking of geometric consistency (mapping and BIM deviation analysis)
2. Building envelope – Checking of thermal performance on 2D components (self-inspection at component level)

Use case 1 has been completed in November 2017, while use case 2 has been finalized in September 2018.

Use case 1: Building envelope – Checking of geometric consistency (mapping and BIM deviation analysis)

Storyboard: Modelling of the existing building

The first use case for the school complex in Pisa consists of the check of the geometric consistency by performing a BIM acquisition and a deviation analysis of the model. This use case is aimed at verifying the safety performance of the building envelope elements, as per Owner's request.

The development of this use case involves the application of the INSITER methodology, in particular Step 1 – Mapping for existing building and Step 3 – Modelling of the existing building.

The main aim is to assess the quality of as-is building performing the deviation analysis to evaluate the 3D models, which have been created on base of the available 2D drawings.

The main steps concerning the application of BIM acquisition for Pisa School Complex are:

- Laser scanning
  - Acquire the geometrical data on the building by laser scanning techniques (on site)
  - Process 3D point clouds
  - Provide 3D point clouds for performing a deviation analysis
- 3D model:
  - Create the 3D model on base of available 2D drawings
  - Create surface model of the 3D model to enable deviation analysis (meshes)
- Deviation analysis
  - Perform alignment process between the point cloud and 3D-model (meshes)
  - Perform deviation analysis
  - Evaluate exactness of the 3D BIM model and optimize model
- Provide further information
  - Generate views and provide reports (results on different supports), available on the INSITER SharePoint.
  - Create TruViews on base of laser scans to provide geometrical information to the site team

The definition of the steps is in accordance with the definitions D5.3 and the validation of the use case has been already completed in November 2017. Some technical results, regarding BIM modelling and deviation analysis, are fully detailed in **D4.2 Model Checking, Clash Detection, and Value Engineering.**

	Description	Responsible partner	Additional input	Time schedule	Tools to be used in the site testing
Step 1	On site - laser scan	AICE	3D point clouds	Done - March/April 2016	Leica laser scanner
Step 2	Process 3D point clouds	AICE	3D point clouds	Done - Nov 2017	n.a.

Step 3	Import point clouds and create shapes	HTV	3D point clouds	Done - Nov 2017	3D Reshaper
Step 4	Create the 3D model	HTV	BIM model	Done - Nov 2017	Revit
Step 5	Perform alignment	HTV	Comparison point clouds/ 3D-model	Done - March 2017	3D Reshaper
Step 6	Perform deviation analysis	HTV	-	Done - April/May 2017	3D Reshaper
Step 7	Reports	HTV	-	Done - Nov 2017	3D Reshaper
Step 8	Create TruViews to provide additional reports on geometry	HTV	-	Done - Nov 2017	Leica Cyclone

Tabel 32: Modelling of the existing building

Use case 2: Building envelope – Checking of thermal performance on 2D components (self-inspection at building component level)

Storyboard: Check of thermal performance

The present use case for the existing school complex involves the assessment of 2D facade panels, to verify the thermal performance of the envelope and identify the presence of thermal bridges, which have been detected using infrared camera. Therefore, the use case is a development of Step 1 – Mapping of the INSITER methodology and can support in the self-inspection phases, such as diagnostic and building assessment, pre-construction, post-construction, and maintenance.

	Description	Responsible partner	Additional input	Time schedule	Tools to be used in the site testing
Step 1	On site	AICE	Thermal images	July 2018	FLIR B60 IR camera
Step 2	Calculation of U values	AICE	n.a.	Sept 2018	n.a.
Step 3	Perform thermal scanning to identify thermal bridges	UNIVPM	AICE	June/Sept 2018	IR camera
Step 4	Calculate thermal bridge incidence factor	AICE, supported by UNIVPM	2D temperature map	June/Sept 2018	INSITER procedures
Step 5	Calculate the real thermal transmittance	AICE, supported by UNIVPM	U values	June/Sept 2018	INSITER procedures

Step 6	Develop refurbishment scenarios and related payback period	AICE	Thermal transmittance, payback period	June/Sept 2018	-
Step 7	Reports	AICE, supported by UNIVPM	Identify inconsistencies in terms of code compliance	Sept/Oct 2018	INSITER tool

Table 33: Check of thermal performance

Connection with other work packages

The results of this work package are the collection of the input from all the work packages about the method, the hardware, the software and BIM. The Pisa demonstration project is described in deliverables D5.3 and D5.4.

Use case 1 Building envelope – Checking of geometric consistency and BIM validation. The mapping and the inspection of building components have been performed in accordance with WP1 methodology, in particular D1.1 and D1.4. The definition of the steps is in accordance with what defined in D5.3, while BIM modelling and deviation analysis are linked to WP4. In particular, **D4.2 Model Checking, Clash Detection, and Value Engineering** provide the final achievements of the use case.

Use case 2: Checking of thermal performance on 2D components. The self-inspection at building component level has been performed in accordance with the INSITER procedures outlined in D5.1 and D5.2. The methodology to implement the activity on site has been applied following the inspection procedures as per D1.5, in order to provide measuring and diagnosis solutions for inspecting building components.

5.3.2 Use case 1: Checking of geometric consistency and BIM validation

The measurement campaign has been performed in March/April 2016 by AICE with the aim to evaluate, using the tools developed in INSITER project, geometric issue on the façade system. The off-site data processing and assessment has been performed by HOCHTIEF using INSITER procedures and finalized in November 2017.

The following activities have been performed:

Mapping: Scan to BIM acquisition (on site)

The step has faced the increasing demand of acquire accurate Building Information Models (BIM) of existing building stock with the AEC sector. Therefore, this use case can be extended for a general procedure within the INSITER guidelines for mapping actual condition via Scan to BIM techniques.

These as-built BIMs are often required to be modelled up to Level-Of-Detail (LOD) 300, and up to Level-Of-Accuracy (LOA) 30. To provide this data, high resolution and high accuracy point cloud data is required.

Data acquisition was performed using a terrestrial laser scanner along with total station measurements.

Two major issues in the procedure have risen:

- Data occlusion: even with high resolution survey data, occluded zones like the interior of walls, floors and ceilings, cannot be avoided. However, a lot of occlusion is caused by the sensors position. Scan to BIM algorithms are forced to make assumptions about these zones, which often lead to misinterpretation. To minimize data occlusion, data coverage should be maximized, and thus, the sensor should be able to access all kinds of spaces.

- Resolution of the survey data: different zones and objects require a certain data resolution in order to be modelled correctly. However, with data resolution inversely proportional to the acquisition speed, the resolution/acquisition time ratio has to be optimized. Acquisition workflows should aim for maximizing speed with a minimum of misinterpretation.

Then, the type of point cloud influences Scan to BIM efficiency. Different survey systems provide varying types of point clouds. Reconstruction algorithms preferably work with structured data, for computational efficiency.

Terrestrial laser scanner has been selected for this use case. Over the last decades, acquisition times have dropped from over half an hour to only a couple of minutes for each scan. This allows for more setups, resulting in larger data coverage. With data acquisition speeds up to a 1,000,000 HZ, weight down to 5-10kg, increased accuracies to up to 6mm/100m, terrestrial laser scanners look stronger than ever.

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Figure 126: Pictures of the field activities performed on site

Figure 127: Pictures of the field activities on site

The technical data of the laser scanner Leica ScanStation C10, which has been used in the field activities, are the following:

- **Instrument type:** Compact, pulsed, dual-axis compensated, high speed laser scanner, with survey-grade accuracy, range, and field-of-view; integrated camera and laser plummet
- **User interface:** Onboard control, notebook, tablet PC or remote controller
- **Data storage:** Integrated solid-state drive (SSD), external PC or external USB device
- **Camera:** Auto-adjusting, integrated high-resolution digital camera with zoom video
- **Accuracy of single measurement**
  - Position: 6 mm
  - Distance: 4 mm
  - Angle (horizontal/vertical): 60 µrad / 60 µrad (12” / 12”)

- **Modelled surface precision/noise:** 2 mm
- **Target acquisition:** 2 mm std. deviation
- **Dual-axis compensator:** Selectable on/off, resolution 1”, dynamic range +/- 5’, accuracy 1.5”

- **Range**: 300 m @ 90%; 134 m @ 18% albedo (minimum range 0.1 m)
- **Scan rate:** Up to 50,000 points/sec, maximum instantaneous rate

- **Scan resolution**
  - Spot size: From 0 – 50 m: 4.5 mm (FWHH-based)
    7 mm (Gaussian-based)
  - Point spacing: Fully selectable horizontal and vertical; <1 mm minimum spacing, through full range; single point dwell capacity.

Scanning speed can be increased even more using Multiple-Pulses-in-Air (MPiA) technology in pulse-based Time of Flight (TOF) laser scanners. Also, the implementation of full waveform analysis has led to more accurate data, effectively removing mixed edge pixels and capturing multiple returns from the laser beam. Furthermore, the capability to capture

RGB data along with LIDAR data is an important asset. While RDB and LIDAR acquisition are currently separated, simultaneous acquisition of RGB and LIDAR is an on-going research but not very affordable for everyday use.

Figure 128: Leica ScanStation and portable device

Terrestrial laser scanning is a multidisciplinary employed system for scanning operations. With its simple tripod setup, the tool can enter any area inside and outside of buildings, and provide high accurate, high resolution point cloud data at increased ranges. For now, terrestrial laser scanners are the only devices capable of providing a standalone solution for the capturing of architectural, engineering and construction projects.

Some innovative and time-saving procedures have been introduced in the self-instructions:

- Eliminating scanner setup, tear-down, and powering off/on between stations saved five minutes per setup, resulting in a time reduction of 36 %. With more than 400 setups, the net savings were significant.
- Using a wireless tablet with a larger display to control scanning, photo capture, and target acquisition provided high visibility for scan quality monitoring and better zooming resolution for critical aiming at targets. In addition, operators were free to roam while scanning and were able to record targets with the tablet while walking to the next location.

Perform alignment and deviation analysis (off site)

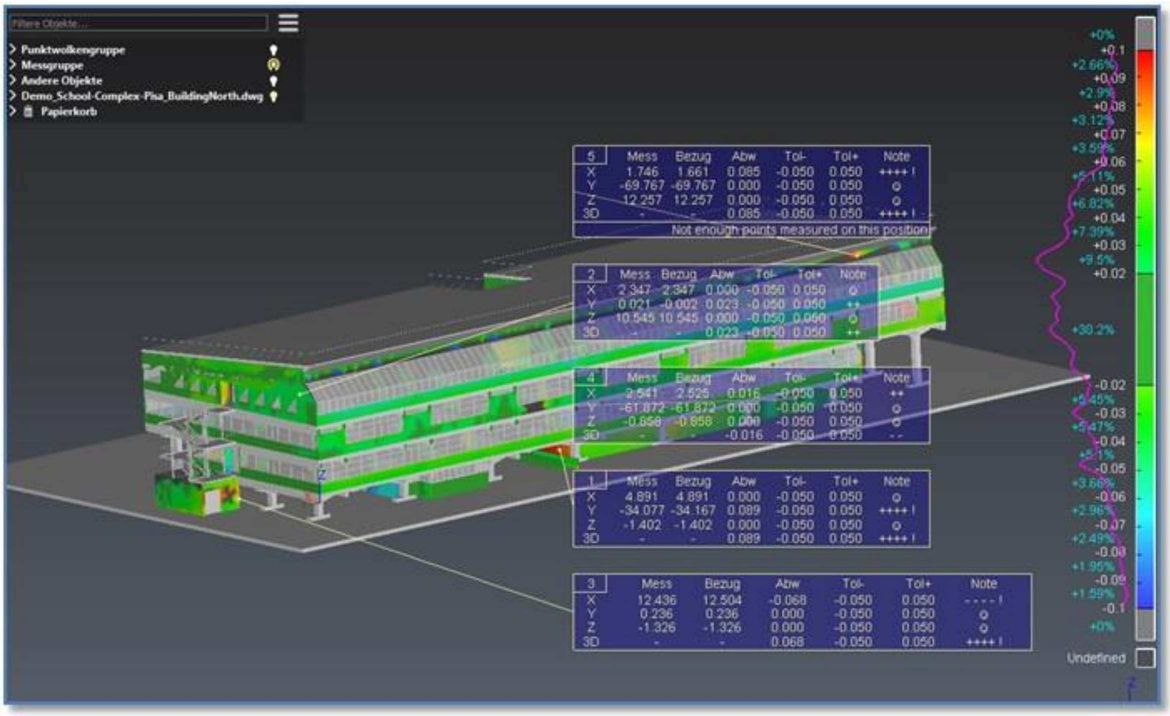


Figure 129: Deviation information of specific points

The deviation analysis has been performed using the 3D Reshaper software and it represents the core activity of use case 1. The deviation analysis process for detecting modelling errors involves several steps.
First, the as-is BIM data and the point data should be aligned, since they had different locations. Ideally, the entire BIM could be compared with the point data in a single operation, but existing software is not capable of handling the large data sets that would be involved and also cannot easily visualize deviations in building interiors.

To address these limitations, we segment a facility into smaller surfaces, such walls, floors, and ceilings of individual rooms, and then conduct deviation analysis separately on each surface. The data for each surface is first segmented from the as-is BIM and the point cloud data.
Then, deviations are computed between the segmented BIM data and the point cloud data. Next, the deviations are visualized in the form of a deviation map. The deviation maps are then analysed to determine the cause of each significant deviation. Finally, the results are summarized and combined with the analyses of other surfaces.

Demonstrated main functionalities of the INSITER applications

The following main functionalities for the INSITER applications have been demonstrated:

- Process of effective BIM modelling (modelling on base of 2D drawings, evaluating the (geometry of the) BIM models on base of laser scans, optimize the BIM models to match the as-is situation
- Re-use laser scans of another laser scanner to create TruViews to support site teams with exact geometrical information (by avoiding that the site team has to use expert software).

5.3.3 Use case 2: Building envelope – Checking thermal performance on 2D components (self-inspection at building component level)

Use case 2 involves the assessment of 2D facade panels, to verify the thermal performance of the envelope using infrared camera. Therefore, the use case is a development of Step 1 – Mapping of the INSITER methodology and can support in the self-inspection phases, such as diagnostic and building assessment, pre-construction, post-construction, and maintenance.

A first analysis has been carried out by standard inspection techniques in April 2016. This analysis has provided only "qualitative" information about the thermal bridge asset. In order to evaluate the thermal bridge impact on the building performance, the following steps have been followed:

- Analyzing plans, sections, details, shop-drawings, as-built and technical documentation (if available) in which the geometric and technological characteristics of the building are reported;
- Visual inspection in situ in order to detect visible areas of mold on the building envelope;
- Use of the infrared camera to detect the most discrete discontinuities at sight. The thermal image is visible, even to unskilled personnel, as well as the heat flow and thermal dispersions associated as pillars in wall, beams, etc.

As already reported in D5.3 and D5.4, the inspections and surveys have been performed by a FLIR B60 camera, capable of capturing the energy emitted by hot bodies (-20 ° C <T <120 ° C) in the form of electromagnetic radiation of the band "infrared" / LW (long wave) and turn it into thermographic image. The analysis has been conducted in the passive voice, i.e. using the direct solar radiation incident on surfaces and natural convective flows.

These are the main tech features of the FLIR B60 camera:

- Temperature range: -20°C to 120°C)
- Temperature accuracy: ±2°C or ±2% of reading
- Image Storage: (1GB micro SD card) 1000 Images
- Emissivity Table: 0.1 to 1.0 (adjustable)
- Field of view/min focus distance: 25° X 25°/0.10m (3.9")
- Thermal sensitivity (N.E.T.D): <0.08°C at 25°C
- Spectral range: 7.5 to 13µm
- Detector Type - Focal plane array: 32,400 pixels (180 x 180)
- (FPA) uncooled microbolometer

In July 2018, AICE has performed 10 additional thermal measurements to check the building envelope, with the technical support from UNIVPM. The investigation has been carried out on different portions of the main building, depending on the floors (first, second and third floors) and the exposure (mainly East, North and West). The survey has detected the temperature of different materials and building components. The pictures below show external and internal view of the facility during the inspection:

East elevation

West elevation

Internal view: window, opaque panel, concrete structure

U glass skylight

Triangle windows

Ribbon windows

Figure 130: pictures taken during internal and external inspection

AICE has followed the instructions to comply with applicable codes and INSITER protocols.
In fact, for each thermal image acquired, the outside air temperature and the indoor air temperature have been measured. Windows and openings were closed. The scales on the thermal image have been set automatically (auto scale). The framing has been carried out in a more frontal way and that the area framed by the camera is also taken with a camera in the visible area. The two images have been taken to result as aligned as possible.
For each thermal measurement, the following data have been exported:

- thermal image in .jpg
- related picture in .jpg
- raw thermal data in .txt

Figure 131: visible and thermal measurement

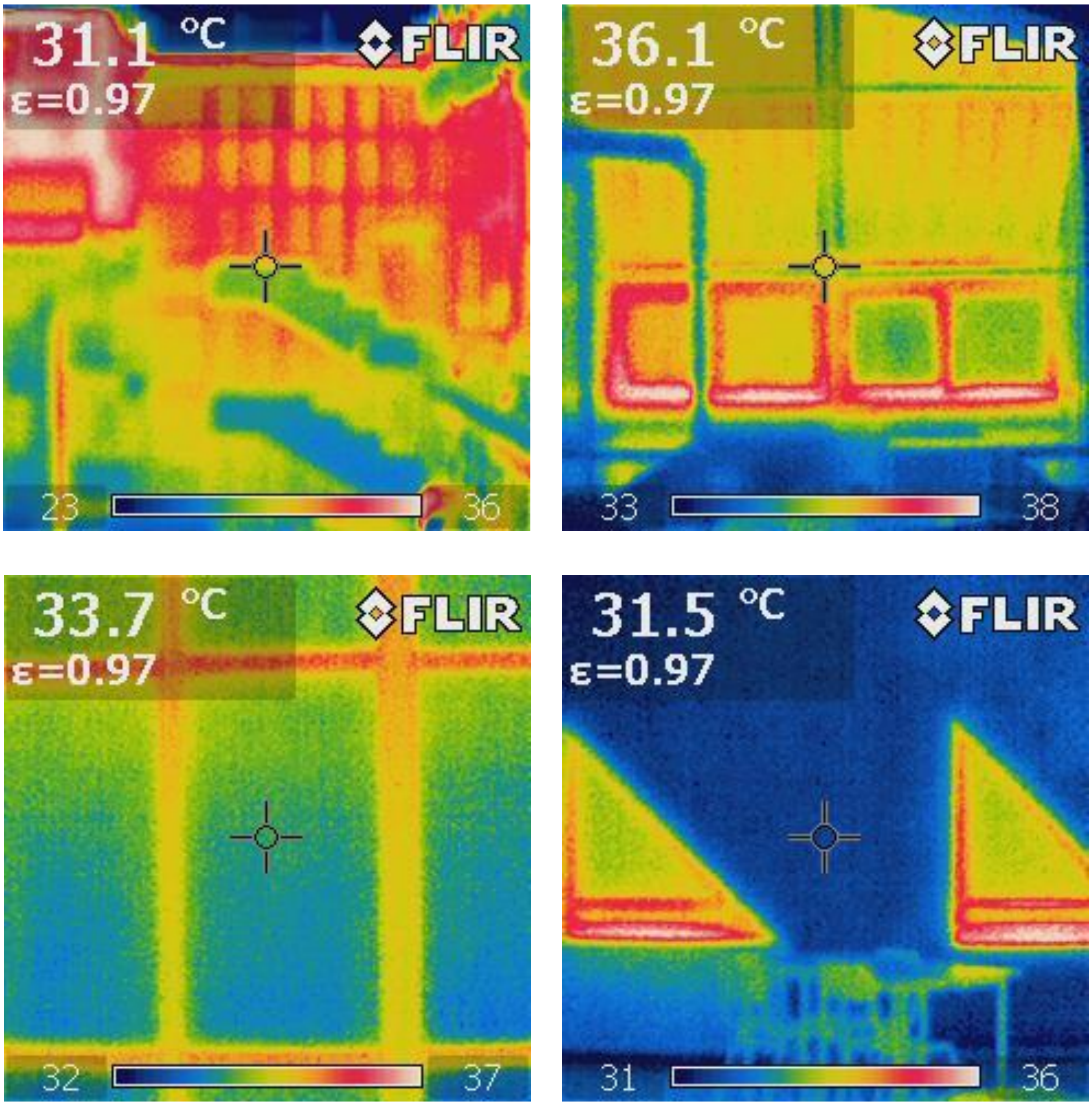


Figure 132: thermal measurement

The collected data are as follows:

Building	**School complex Concetto Marchesi, Pisa, IT**
Date	27 Jul 2018
Outside temperature T_e	31.5 °C
Weather conditions	Partly cloudy

Internal measurements:

M n. 1	
Floor	First floor
Room ID	Photocopy laboratory
Facade Exposure	East
Room temperature	31 °C
Window frame temperature	35.5 °C
Glazed panel temperature	33.5 °C
Opaque panel temperature	32 °C

M n. 2	
Floor	First floor
Room ID	Staircase
Facade Exposure	West
Room temperature	29.5 °C
Window frame temperature	31.2 °C
Glazed panel temperature	30.5 °C
Reinforced concrete temperature (structure)	28.5 °C

M n. 3	
Floor	First floor
Room ID	Classroom 2 (corner)
Facade Exposure	East
Room temperature	32 °C
Window frame temperature	36.5 °C
Glazed panel temperature	34 °C
Opaque panel temperature	32.4 °C

M n. 4	
Floor	First floor
Room ID	Classroom 2 (corner)
Facade Exposure	North
Room temperature	32 °C
Window frame temperature	32.6 °C
Glazed panel temperature	32.1 °C
Opaque panel temperature	29.9 °C
Reinforced concrete temperature (structure - beam)	30 °C

M n. 5	
Floor	Second floor
Room ID	Staircase
Facade Exposure	West
Room temperature	31 °C
Window frame temperature	33.5 °C
Glazed panel temperature	32 °C

M n. 6	
Floor	Second floor
Room ID	Drawing room
Facade Exposure	East
Room temperature	32 °C
Window frame temperature	36.7 °C
Glazed panel temperature	34.5 °C
Opaque panel temperature	34 °C

M n. 7	
Floor	Third floor
Room ID	Room 16
Facade Exposure	East
Room temperature	33.5 °C
Window frame temperature	36.3 °C
Glazed panel temperature	35.6 °C
Opaque panel temperature	33.5 °C
U glass skylight	35.7 °C

M n. 8	
Floor	Third floor
Room ID	Staircase
Facade Exposure	West
Room temperature	32.3 °C
Window frame temperature	35 °C
Glazed panel temperature	33.5 °C

M n. 9	
Floor	Third floor
Room ID	Room 23 (corner) – ribbon windows
Facade Exposure	East
Room temperature	33.8 °C
Window frame temperature	36.1 °C
Glazed panel temperature	34.9 °C
Opaque panel temperature	33.7 °C
U glass skylight	35.2 °C

M n. 10	
Floor	Third floor
Room ID	Room 23 (corner) – triangle windows
Facade Exposure	North
Room temperature	33.8 °C
Window frame temperature	35 °C
Glazed panel temperature	33.2 °C
Opaque panel temperature	31.6 °C

Table 34: Measurement overview

The thermographic investigation of the building envelope evidences that the methodology based on IR camera is very powerful since it is able to visualize any area of the wall exhibiting a different emission. In fact, parts of the envelope made of different materials or having different colours are recognizable due to their different emissivity. The INSITER procedure for thermal bridges localization can be applied to the maps registered but, unfortunately, an important requirement prescribed by the procedure is that the thermal gradient between outdoor and indoor must be at least of 10°C, as it can be seen from the temperature data reported in the previous table. This requirement would have been achieved only if the building had been conditioned but this has not been possible since it will have to be decommissioned. Since the building must be renovated or demolished the easiest way to estimate its thermal performance is to calculate the thermal transmittance of the wall by a drilling to identify its stratigraphy. AICE worked a survey in the opaque panel, drilling a hole in the panel. From this partially destructive investigation, used ONLY as verification, it emerged that in reality the panel does not have an insulating layer in the core but consists of a homogeneous concrete panel, about 20 cm thick (see pictures below).

The drilling of the opaque panel

The wall panel from the inside

Figure 133: Drilling of the panel

Measurement of the thickness of the concrete panel

Figure 134: Documentation of measurements

The thermal transmittance can be calculated from the stratigraphy following the UNI EN ISO 6946:2008

The calculated thermal transmittance of the panel is 3.817 W/m2K.

The calculations have been carried out by commercial software MC4 and consist of:

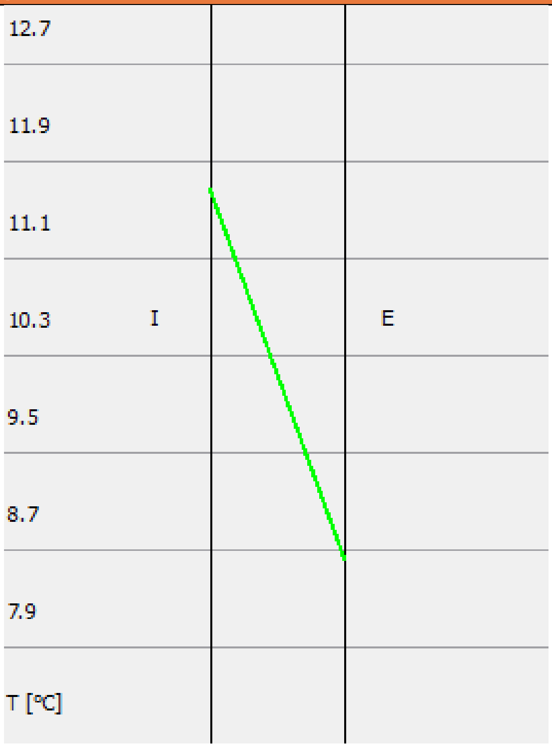
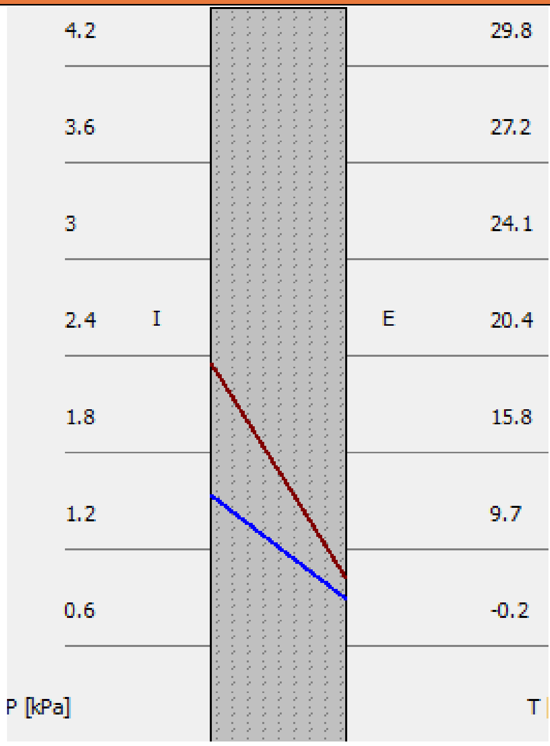
1. Calculation of thermal transmittance
2. Calculation of the surface temperature and the interstitial condensation of building structures
3. Verification of the thermal inertia

See the output of calculation below.

Calculation of thermal transmittance (UNI EN ISO 6946:2008)

Building component: concrete panel, 23 cm thick

Density	D	[kg/m³]
Thickness	s	[cm]
Indicative reference conductivity	λ	[W/(m·K)]
Calculated conductivity	λ_m	[W/(m·K)]
Percent increase	m	[%]
Unit thermal resistance	r	[(m²·K)/W]
Thermal difference	dT	[°C]
Surface temperature downstream of the layer	Tf	[°C]
Saturation pressure of water vapor	Ps	[kPa]
Resistance to vapor passage	μ	-
Resistance to the vapor flow of the layer	Rv	[m²sPa/kg]
Pressure difference	dP	[kPa]
Partial pressure of water vapor	Pv	[kPa]
Aeric mass of the layer	Ds	[kg/m²]
Massive thermal capacity of the layer material	CT	[kJ/(kg·K)]
Thermal capacity of the layer by unitary variation of the ambient temperature	CTs	[kJ/m²]

Temperature	Pressure
	

Technical features of the building component

Ti	Te	U.R.(i)	U.R.(e)	Wind
[°C]	[°C]	[%]	[%]	[m/s]
20	7.3	65	87	0

STRATIGRAPHY

Material description	D	s	λ	m	λ_m	r	dT (*)	Tf	Ps	μ	Rv	dP	DS	Pv	CT	CTS
Indoor ambient air								20	2.34							
Inner liming layer						0.250	8.3	11.7	1.37							
Concrete	2400	23	2.5	0	2.5	0.092	3.1	8.6	1.02	130	159.5	0.63	552.00	0.89	1	304.90
Outer liming layer						0.040	1.3	7.3	1.02							
TOTAL:		**23**				**0.382**							**552**		**304.90**	

Theoretical transmittance:	[W/(m²·K)]	3.817
Increase factor (10[%]):	[W/(m²·K)]	4.199
Rounding:		0.001
Thermal transmittance:	[W/(m²·K)]	4.198

(*)The differences in temperature in the various layers are obtained with an internal surface heat resistance of 0.25 [(m² · K) / W] as foreseen by Prospect 2 of UNI EN ISO 13788.

COMPARISON WITH LIMIT VALUES		
The opaque structure is of the type	**Vertical**	
Calculated transmittance of the building element	**3.817**	[W/(m²·K)]
Limit value of transmittance (Italian energy regulation)	**0.340**	[W/(m²·K)]

Calculation of the surface temperature and the interstial condensation of building structures (UNI EN ISO 13788:2003)

Ma	Vapor mass per unit of accumulated surface at an interface	[kg/m²]
R	Specific thermal resistance	[(m²·K)/W]
T	Temperature	[°C]
Mu	Hygroscopic resistance factor	
FRsi	Temperature factor at the inner surfacea	
FRsi,min	Design temperature factor at the inner surface	
S	Thickness	[cm]

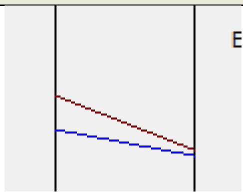
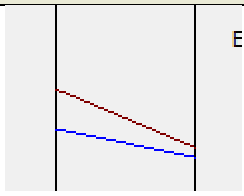
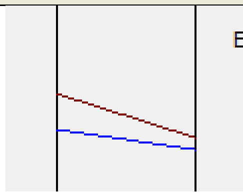
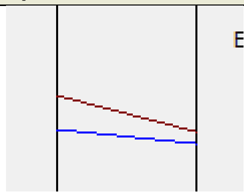
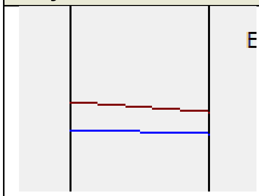
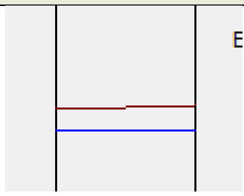
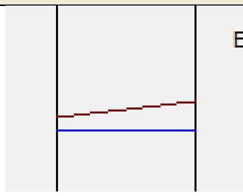
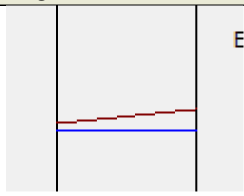
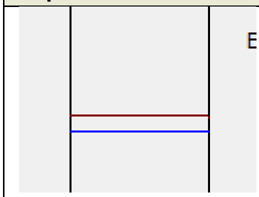
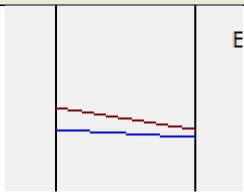
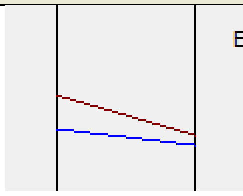
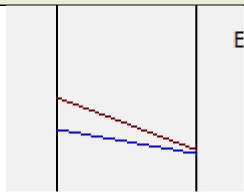
Concrete panel, 23 cm thick			
Material	**Mu**	**R**	**S**
		[(m²·K)/W]	[cm]
Concrete	130	0.092	23
		Total: (*)	**Total:**
Quality factor = 0.3460		**0.262**	**23**

(*)In the calculation of the total thermal resistance, the thermal resistances of the internal and external liminal layers defined in the archive are included.

The hygrometric verification is performed with the thermal resistances of the liminal layers provided in the Schedule 2 of UNI EN ISO 13788.

Results from calculation										
Month	**Te**	**URe**	**Ti**	**Uri**	**Pe**	**Pi**	**Tmin**	**FRsi**	**Gc**	**Ma**
	[°C]	[%]	[°C]	[%]	[kPa]	[kPa]	[°C]		[kg/m²]	[kg/m²]
Jan	7.3	87	20	65	0.89	1.52	16.7	0.7390		
Feb	7.4	78	20	61	0.8	1.43	16.7	0.7370		
March	10.7	80	20	64	1.03	1.49	16.7	0.6440		
April	12.9	78	20	65	1.16	1.52	16.7	0.5340		
May	17.9	73	20	69	1.5	1.6	16.7			
June	20.6	73	20	76	1.77	1.77	16.7			
July	22.9	69	20	83	1.93	1.93	16.7			
August	23.1	75	20	90	2.11	2.11	16.7			
Sept	19.8	80	20	80	1.85	1.86	16.7			
Oct	15.6	86	20	75	1.53	1.74	16.7	0.2470		
Nov	11.7	81	20	65	1.11	1.52	16.7	0.6010		
Dec	7.6	88	20	65	0.92	1.53	16.7	0.7330		

Verification IAW applicable standards
1) The amount of condensate does not exceed 0.5 kg / m².
2) The amount of condensate is limited to the re-evaporable quantity.
3) The structure is subject to superficial condensation phenomena
THERMOIGROMETRIC CHECK: ***X***

Graphical summary of the months			
Jan	**Feb**	**March**	**April**
			
May	**Jun**	**Jul**	**Aug**
			
Sept	**Oct**	**Nov**	**Dec**
			

Verification of the thermal inertia (UNI EN ISO 13786:2008)

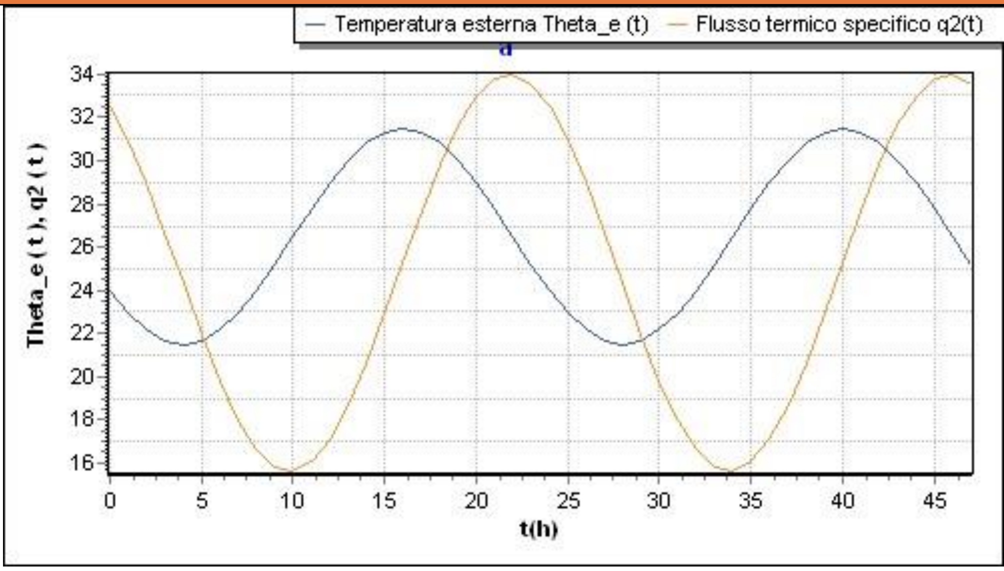
Thermal conductivity *(*)*	λ	[W/(m·K)]
Thickness	d	[cm]
Specific thermal capacity	c	[kJ/(kg·K)]
Density	ρ	[kg/m³]
Surface thermal resistance	R	[(m²·K)/W]
Depth of periodic penetration	δ	[m]
Ratio between the thickness of the layer and its periodic penetration depth	ξ	-

(*) Thermal conductivity including the possible increase factor, according to the UNI EN 10351 standard

STRATIGRAPHIC COMPOSITION AND THERMAL PROPERTIES							
DESCRIPTION	λ_j	c_j	ρ_j	d_j	R_j	δ_j	ξ_j
	[W/(m·K)]	[kJ/(kg·K)]	[kg/m³]	[cm]	[(m²·K)/W]	[m]	-
Internal surface resistance R_{s1}					0.130		
Concrete	2.50	1.00	2400	23.00	0.092	0.17	1.36
Internal surface resistance R_{s2}					0.040		

REAL "LIGHT" STRUCTURE - THERMAL AND DYNAMIC CHARACTERISTICS			
X_1	Internal areic thermal capacity	[kJ/(m²·K)]	89.79
X_2	External areic thermal capacity	[kJ/(m²·K)]	187.38
T	Period for the calculation of dynamic parameters	s	86400
$\lvert Y_{ee,12,l} \rvert$	Periodic thermal transmittance	[W/(m²·K)]	1.839
U_l	Thermal transmittance in steady state	[W/(m²·K)]	3.82
f_l	**Damping factor**	**-**	**0.48**
$t_{s,l}$	**Time shift**	**h**	**5.79**
$M_{s,l}$	Surface mass	[kg/m²]	552.00

LIGHT STRUCTURE GRAPH



Verification as per Italian Energy Regulation (D.P.R. N.59 del 02/04/2009)

symbol	description	u.m.	structure		comparison value	partial outcome	final result
M_s	Surface mass	Kg/m²	552.00	≥	230	V	
$\|Y_{ee,12}\|$	Periodic thermal transmittance	W/(m²K)	1.839	<	0.120	X	
Summary of the summer requirements for regulatory standards							X
	Legend: *V* = verified – *X* = not verified						

Further analysis on the building envelope and refurbishment scenarios

On the basis of the collected data, AICE has also carried out a similar thermal simulation with design new condition: the analysis has been carried out by installing an external insulation for the opaque panels, consisting of 15 cm thick expanded polystyrene panels. This thickness allows compliance with the transmittance values for the building envelope as per applicable standards.

A comparison was also made between current energy consumption and those after the intervention, and the payback period was calculated. The following data summarize the calculation:

- Air-conditioned net volume (approximated assuming 3m of inter-floor space): 59,847.89 mc (19,949.30sqm)
- Estimated current energy consumption: 2,210,374.90 kWh / year, i.e. 36.93 kWh / m^3 year
- Estimated requirements following adaptation of the transmittance of opaque structures (install insulation): 680,393.36 kWh / year, ie 11.37 kWh / m3 for an estimated investment of: € 3,190,283.67.
- The savings are € 122,398 per year. The payback period is approximately 26 years.

An additional design scenario has been developed, considering the replacement of the windows:

- Estimated requirements following adaptation of the transmittance of transparent elements (replace windows): 404790.61 kWh / year, i.e. 6.76 kWh / m^3 for an estimated investment in: € 3,273,390.23
- The savings are € 144,446 per year. The payback period is approximately 23 years.

The cost estimate only focused on the envelope and does not take into account the additional cost to "adapt" or replace the existing HVAC system. The simulation scenarios showed that the effort for refurbish the building envelope and to upgrade to current energy standards is very significant.

The inspections and simulations carried out using the INSITER methodologies were of fundamental importance for defining the refurbishment scenarios.

These results constituted the decision-making basis for the building owner to plan the interventions on the building.

Demonstrated main functionalities of the INSITER applications

The following main functionalities for the INSITER applications have been demonstrated:

- Self-inspection support for mapping and inspection phase: capture the actual on-site condition, Mapping actual technical conditions of the site and building, and performing economic valuation to support the calculation of refurbishment scenarios;

5.3.4 Conclusions

Compliance with Key Performance Indicators

The geometric consistency and the building thermal performance are two significant Key Performance Indicators to provide information about the energy efficiency of the building. If the existing building envelope presents any irregularities in geometry and/or in thermal properties, the building thermal behaviour can be affected and cause energy losses and an increase in the annual energy consumption. The assessment of these KPIs can be used to develop possible refurbishment scenarios, considering the project goals (e.g. refurbishment that also includes an upgrade of the energy label), payback periods and time schedule.

In particular, the thermal measurements can provide information on the actual technical features of the envelope when details/data on the original building components are missing. In fact, thermal maps registered on the building envelope of the demo case in Pisa did not highlight any thermal bridge that is not connected with the different thermal emissivity of the material of the building facade. Nevertheless, the thermal transmittance calculated using the stratigraphy of the wall show that its value (3.8 W/m2K) is higher than the estimated one (1.2 W/m2K). This surplus of thermal transmittance affects substantially the energy performance estimation of the building

Improvement and lessons learned

The main goal of the demo case was to capture as-is situation of the building envelope and provide refurbishment scenarios to be compared, considering that no information on the building was available except from some 2D drawings. The building physics analysis (U-value, sound insulation) and the indoor climate analysis was outside the scope of the present demo case, which main goals were to address:

- Poor safety performance of the building envelope elements. In particular, liability of non-structural elements (prefab panels), that could collapse and cause injuries to the building occupants.
- Poor energy performance of the building envelope (prefab opaque panels, U-glasses of skylights, waterproofing layers), due to bad condition.

The first phase of mapping has been developed using INSITER methodologies to improve and enhance standard practices; the second part, i.e. the development of possible scenarios, mainly refers to design and therefore is not included in the INSITER, but the INSITER procedures during on site measurements and off site simulations have speed up the elaboration of different design options.

Thus, AICE (as SME of building inspectors and engineers) has been able to capture the requirements and provide effective design solutions to the Building Owner, based on actual condition of the building envelope.

From the geometric analysis and the calculation of deviation analysis (Use case 1) of this demo case, it has been learned that is not efficient to model on base of point clouds, since this would need too much computing power, because those point clouds are very large and hard to handle. The exactness of the point clouds cannot be transferred into a 3D model and therefore abstractions would be needed (cracks and really minor changes of surfaces are included in the point clouds, but should not be included in a BIM model). In addition, lots of items which are shown in laser scan are not relevant for the BIM model itself – this abstraction makes modelling very hard and time-consuming.

There are approaches to automate the BIM object creation (e.g. for pipes and ducts), but the effort to validate if those items have been correctly been transferred from points to BIM objects, is far greater than modelling the objects on base of 2D drawings. Finally, it has been found that deviation analysis is a great tool to validate the correctness of available 3D data.

From the thermal inspections and the calculation of the transmittances (Use case 2) of this demo case, it has been learned that, according to the test conditions (mainly environmental ones) and the type of the building (new construction or renovation), it is possible to adopt the most appropriate technique and test procedure that allows having the best compromise between expectations, available resources and time. In this demo case, an analysis of the test conditions (season, possibility of conditioning, etc.) and the condition of the building under renovation made it possible to establish that the fastest, least expensive and less invasive method was the drilling coupled with analytical calculation.

6. Real demonstration case of large maintenance / monitoring in Valladolid, ES

6.1 Changes compared to the original plan described in D5.3

No changes

6.2 Field validation / demonstration procedures for each use case

The detailed description of CARTIF-3 building (Boecillo, Valladolid, Spain) was provided in D5.3. The prefab panels made envelope has been designed to minimize thermal energy such as heating and cooling and also light electrical demand through a special concept (glass wall and louvers blinds). This allows an important use of daylight (high solar gain), reducing thermal requirements and obtaining highly insulation in the different elements of the envelope.

The use of louvers involves a decrease around 30% in the cooling demand which confirmed the decision of not to install a cooling system, but a free-cooling system. This is a great saving in both the investment cost and the operational cost. To ensure this is still true, the analysis of deviations of the louvers' current status with respect to the initial project, as well as the inspection of the critical parts of the external envelope by means of the combination of 2D / 3D information using the INSITER -DLL tool, is being performed for maintenance tasks in such a type of buildings.

There is a polygeneration renewable energy facility, designed as a combination of thermal plants (using geothermal and biomass integrated systems) that will ensure high efficiency, energy balances between winter and summer periods (by means of the use of the ground storage capacity) and zero CO2 emissions. Also in the building it is installed high efficiency lightning.

The HVAC system for the CARTIF-3 building is entirely based on renewable energy production to provide the energy needs. The energy sources are geothermal and biomass, achieving a significant reduction of CO2 emissions. Another important applied measure consists on the installation of a Photovoltaic (PV) plant in order to supply an important portion of the total electricity consumption. It allows a contribution of 15kWh/m2yr. The photovoltaic plant of CARTIF-3 has the solar panels directed to the south with 30º tilt and free of shadows.

The heating and cooling system has been studied and chosen independently for the offices areas and the industrial areas, because they are very different uses and sizes. All the necessary thermal energy for the industrial areas and the domestic hot water (DHW) will be provided by a biomass boiler with very high performance (> 90%), with the added value of having zero CO2 emissions. Moreover, two solar thermal systems (15 and 16 panels, 37.5 m2 and 32 m2, respectively) are included in the building for the DHW, but also for radiant floor needs. Two combined flat plate collectors are installed with independent loops. Furthermore, four storage tanks are available of 2000 litres each one for a total of 8000 litres which are used to provide hot water to the heating system (inertia tanks) and an additional one of 500 litres for the main purpose of the DHW feeding.

An advanced building management systems (BMS) is currently running to optimize energy uses. This system allows not only reading but also storing monitoring information in a data base that will be integrated in the final INSITER toolset as reference and example for proper inspection of the performance of the solar thermal system during its life-span taking in to account the specifically related thresholds and KPIs. Quantitative analysis of the KPIs will be needed not only in the final deliverables of WP1 (i.e. D1.5 and D1.7), but also in presenting the field validation results in WP5.

Use cases 1 and 2 point out complementary procedures and tools for self-inspection, so they do not have KPIs and specific thresholds directly linked to energy efficiency. These apply on use case 3, which were properly indicated in section 3.3.3 of D5.3: Case study elaboration, field validation protocols, and equipment calibration: Table 2: Solar thermal system KPI's; Table 3: Solar thermal pumping system KPI's; Table 4: Solar thermal storage system KPI's. Some illustrative figures can also be found in D5.3 for the proper definition and monitoring of energy KPI (Figure 75 and Figure 76) in addition to the proper definition and monitoring of comfort KPI (Figure 77).

6.2.1 Use Case 1: Application of 3D laser surveying for checking and approval of geometrical deviations

It has been demonstrated at CARTIF-3 building as INSITER use case that 3D laser surveying point clouds and derived models are readily improving building projects by analysing clashes by evaluating:

- The current situation prior to refurbishment or corrective maintenance operations, or
- Previously/newly designed elements and existing conditions.

For further details, please see *section 3.3.1: Use Case 1, check and approval of measured values (self-inspection at component level)* of D5.3.

The procedure can be extended to energy efficient buildings made of prefabricated panels performing the steps indicated in the following use case:

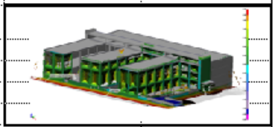
INSITER D5.4; data sheet use case					
Use Case 2.1		**Check and approval of measured values**			
Relevant Demonstrator		CARTIF-3 Building			
Responsible Insiter Parter		CARTIF			
	Description	responsible partner	additional input	timeschedule	tools to be used in site testing
Step 1	Create CAD/BIM Model	CARTIF, construction or architectural company	n.a.	CAD done / BIM almost finished version	CAD / IFC viewer
Step 2	Upload CAD/BIM to server	HVC	n.a	CAD done / BIM preliminar version	n.a.
Step 3	On-site 3D data acquisition (laser scanning or photo scanning)	CARTIF, surveying company	n.a	done	Laser scanner / Hi-tech photocamera / Point cloud viewer
Step 4	3D processing, editing and registering: useful point clouds obtention & accuracy assessment (by feature modelling)	CARTIF, surveying company	n.a	done	
Step 5	Upload relevant point cloud/s to server	CARTIF, HVC, building owner/manager		done	INSITER guidelines
Step 6	Fixing tolerance thresholds: positive (Hi+; Lo+) and negative levels of (Hi-; Lo-)	Construction or architectural company	owner / manager feedback	done	
Step 7	Computing deviations in the nominal -shortest-direction between the reference model (CAD/BIM) and the data model (point cloud)	CARTIF, surveying company	Sw tool supporting reverse-engineering workflows	done	Reverse-engineering tool viewer
Step 8	Check, report & analysis of results: current status of the building made of prefab components	CARTIF, 3L, DEMO	owner / manager feedback		INSITER software tool

Table 35: data sheet use case 2.1

The technologies, techniques, related hardware and software, file formats and partners (inside and outside the consortium) that are needed are adequately indicated. No more geometric deviation tests are expected in CARTIF-3, being open to advise those who are willing to perform them in their corresponding demonstrator (HCC in Cologne is a complementary example).

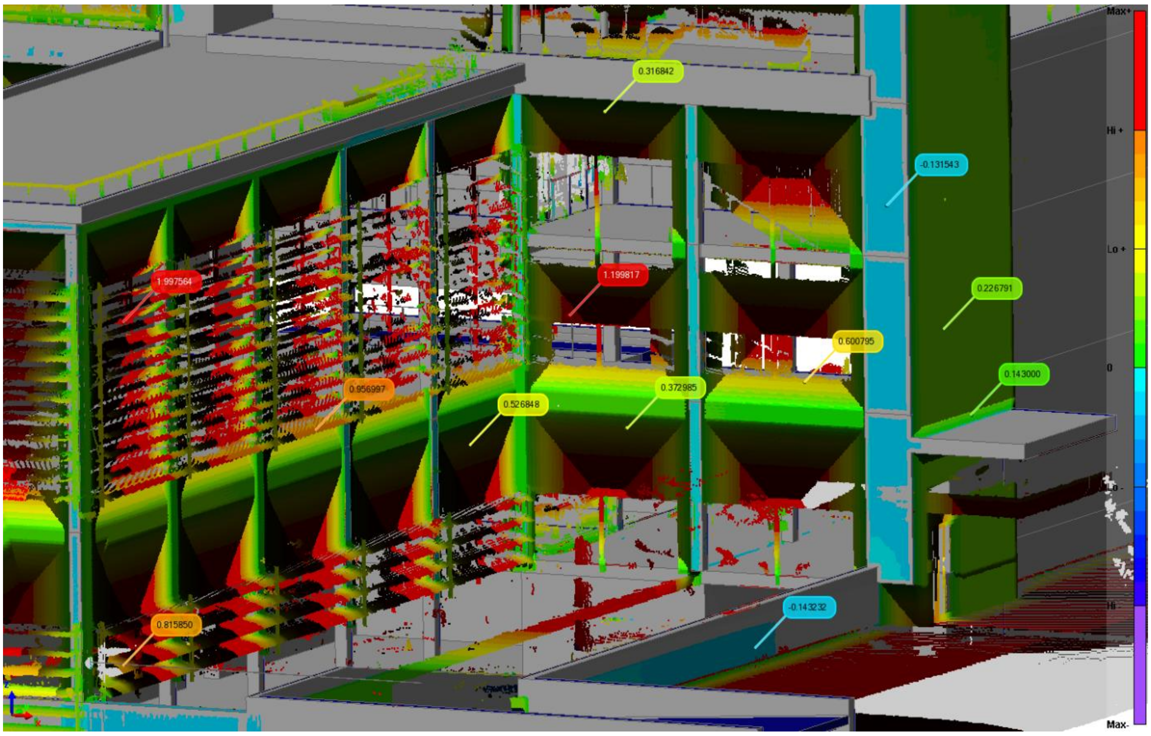


Figure 135: Marking of deviations on points of interest according to scale. CARTIF-3 on-site visualization example using

6.2.2 Use Case 2: Application of the INSITER-DLL to aid assessing building envelope quality

To help the self-inspection procedure, the tailored INSITER-DLL plug-in allows combining 2D & 3D relevant information (geometry, colour, reflectivity, thermography, and sound map) to be managed into REVIT through PLY point clouds.

The INSITER-DLL tool has been successfully tested for the analysis of the CARTIF-3 envelope. Further details are easily found in *section 3.3.2: Demo Case 2, building envelope quality (Self-inspection at building level)* of D5.3. It has been recently improved and adapted to the REVIT'2018 version following the indications of skilled partners. Some bugs are fixed as well (especially for scaling to import point clouds). The INSITER-DLL is in continuous evolution for proper performance to REVIT updates.

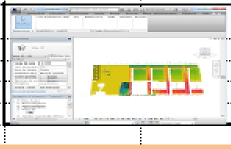
The complete process into which the INSITER-DLL takes part, applied in a general way to energy efficient buildings made of prefabricated panels is fully described in the following use case:

INSITER D5.4; data sheet use case

Use Case 2.2 — **Building envelope quality**

Relevant Demonstrator: CARTIF-3 Building

Responsible Insiter Parter: CARTIF



	Description	responsible partner	additional input	timeschedule	tools to be used in site testing
Step 1	3D laser scanning / photo-scanning of representative elements / areas /envelope of EE buildings made of prefab modules: geometry (XYZ coordinates); colour (RGB coordinates: real appearance); reflectance (L index: materials and humidity).	CARTIF, surveying company	owner / manager feedback	done	Laser scanner / Hi-tech photocamera / Point cloud viewer
Step 2	Processing the L index according to a tailored algorithm for moisture checking	CARTIF	n.a	done	n.a.
Step 3	3D data processing, editing and registering: useful point clouds	CARTIF, surveying company	n.a	done	Reverse-engineering tool viewer
Step 4	Upload relevant point cloud/s to server	CARTIF, HVC, building owner/manager		done	INSITER guidelines
Step 5	Thermography imaging where needed within the scanned area/s (to assess heat gain/loss and thermal bridges)	CARTIF, UNIVPM, energy engineering or consultant	owner / manager feedback	done	Thermal camera
Step 6	Acoustic imaging where needed within the scanned area/s (to assess comfort conditions - noise is wasted energy-)	SIEMENS, construction engineering or consultant	owner / manager feedback		Sound brush
Step 7	Mapping images on 3D point clouds in a raster-based process	CARTIF, SIEMENS		done	MeshLab free open source tool or eq.
Step 8	Exporting the previous enriched 2D/3D mapping as PLY. As many PLY files as needed are created (a single PLY file per mapping)	CARTIF, SIEMENS		done	MeshLab free open source tool or eq.
Step 9	Using the specially tailored INSITER-DLL plug-in to precisely displaying the PLY files by layers into REVIT (a specific toolbar is created).	CARTIF, HVC, DEMO, 3L, construction engineering or consultant		done	REVIT & INSITER-DLL plug-in
Step 10	Using of PLY files to aid drawing BIM parametrical features to be taken into account as part of a REVIT project	CARTIF, HVC, DEMO, 3L, construction engineering or consultant			REVIT & INSITER-DLL plug-in
Step 11	Upload the resulting unique working project (RVT/RFA/IFC converted files) to server	CARTIF, HVC, building owner/manager		done	INSITER guidelines
Step 12	Check, report & analysis of building envelope quality	CARTIF, 3L, DEMO	owner / manager feedback		INSITER software tool

Table 36: data sheet use case 2.2

Apart from CARTIF-3 building, those complementary pilot sites requiring envelope quality assessment will try the INSITER-DLL plug-in, supporting feedback for further improving.

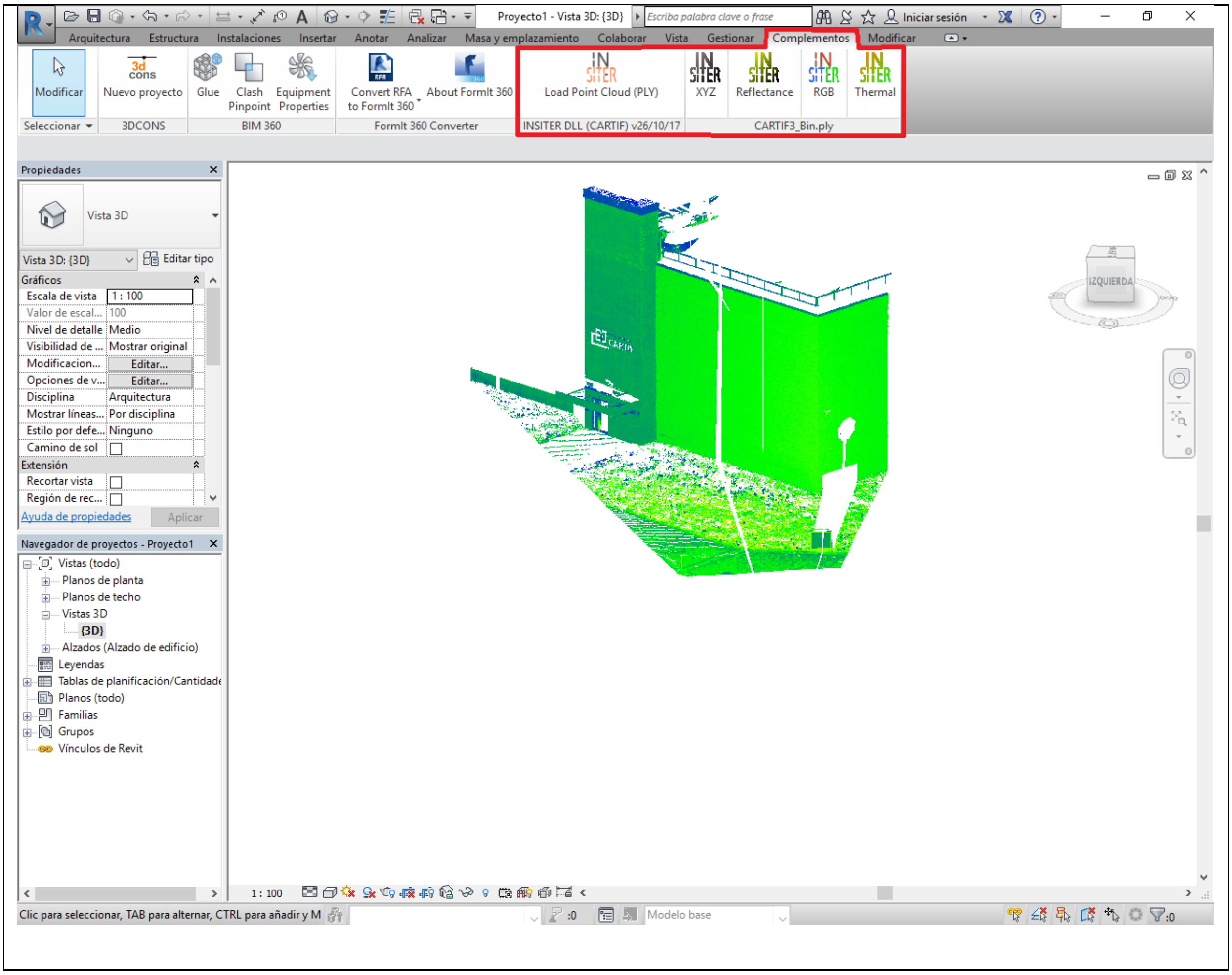


Figure 136: INSITER-DLL plug-in improved and updated to REVIT'2018

6.2.3 Use Case 3: Application of a procedure for commissioning of solar thermal systems

Solar thermal systems are very relevant on EE issues, and are representative for the case of buildings made of prefab elements. In accordance with *section 3.3.3: Demo Case 3, commissioning of the solar thermal system (Self-inspection & Self-instruction)* of D5.3, three issues have to be taken into account:

- Verify if the components of the solar system (solar collectors, pumps, plumbing, heat exchanger, thermal storage and controllers) are in accordance with the purchase requirements;
- Validate that the installation of the solar thermal system has been done in the proper way and the commissioning of the installation has been performed correctly;
- Surveillance the performance of the solar thermal system during its life-span taking into account specifically related thresholds and KPI coming from continuous monitoring.

CARTIF-3 building is the only demonstrator of the project to fit these three issues. For the first point, CARTIF provides support based on its recognised experience. Regarding the second point, CARTIF-3 building includes a solar thermal system that is working for a while, hence, checklists and installation information may be provided. Finally, about the third point, KPIs are already provided. Tasks related to prioritization of alarms, the implementation of KPIs and alarm rules into the INSITER tool, and also making monitoring data to be available in the INSITER tool are planned to be performed until March 2018.

Computing KPIs and check deviations between actual and desired operation will be evaluated throughout continuous remote monitoring until the end of the INSITER project, but it is worthy of remark that the continuous monitoring has been working from the past until now and will continue working far ahead the project ends.

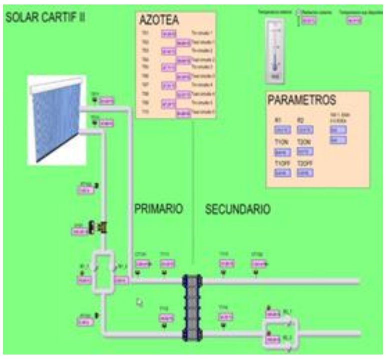


Figure 137: Monitoring schema of the solar thermal system in CARTIF-3 building

The overall performance process is fully described in the following use case data sheet:

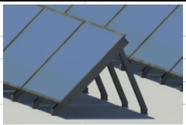
INSITER D5.4; data sheet use case					
Use Case 2.3		**Commissioning of the solar thermal system**			
Relevant Demonstrator		CARTIF-3 Building			
Responsible Insiter Parter		CARTIF			
	Description	responsible partner	additional input	time schedule	tools to be used in site testing
PREPARATION OF INFORMATION INTO THE INSITER TOOL					
Step 1	Include solar thermal system into BIM model	CARTIF		ongoing	
Step 2	Provide and upload technical information (2D/3D installation schemes, panel specs, etc.) and self-instruction guidelines in INSITER server	CARTIF	technical specifications from manufacturer/provider	ongoing	
Step 3	Provide bar/QR code linked to panel information in INSITER server	CARTIF	technical specifications from manufacturer/provider	n.a *	
VERIFICATION					
Step 3	Scan bar/QR code	CARTIF (responsible for reception)	-	n.a *	bar/QR code scanner
Step 4	Check specifications and visual inspection	CARTIF (responsible for reception), installer	-	n.a *	
Step 5	Accept/Reject panel system according to invoiced (before installation)	CARTIF (responsible for reception)	-	n.a *	INSITER software tool
INSTALLATION: SELF-INSTRUCTION AND COMMISSIONING					
Step 6	Check of glycol/water mixture concentration for antifreeze protection	Installer	-	n.a *	INSITER guidelines
Step 7	Filling process according to INSITER self-instruction guidelines	Installer	-	n.a *	INSITER guidelines
INSTALLATION: SELF-INSPECTION DURING PRE-COMMISSIONING					
Step 8	Geometrical tests based on 3D laser scanner	Installer	-	March 2018	INSITER guidelines
Step 9	Thermal tests based on thermography	Installer	-	March 2018	INSITER guidelines
Step 10	Pressure tests	Installer	-	n.a *	INSITER guidelines
Step 11	Accept/Reject panel system installation according to INSITER guidelines	CARTIF (responsible for reception)		February / March 2018	INSITER software tool
SURVEILLANCE AND CONTINUOUS COMMISSIONING: SELF-INSPECTION DURING MAINTENANCE					
Step 12	Definition of indicators and tolerance thresholds for critical operation variables	CARTIF	owner / manager feedback	February 2018	
Step 13	Prioritization of alarms	CARTIF	-	April 2018	
Step 14	Implementation of indicators (KPIs) and alarm rules into the INSITER tool	CARTIF, DEMO	-	January / February 2018	
Step 15	Making monitoring data available in the INSITER tool	CARTIF, DEMO	-	April / May 2018	Existing monitoring, INSITER software tool
Step 16	Computing KPIs and check deviations between actual and desired operation	CARTIF, 3L, DEMO	owner / manager feedback	May 2018	INSITER software tool
Step 17	Report & analysis of results: current status of the solar panel system	CARTIF, 3L	owner / manager feedback	June 2018	INSITER software tool
*	*Solar panels in CARTIF-3 demo building already exist and are already installed.*				

Table 37: data sheet use case 2.3

The use case 2.1 is developed in D5.3. The use case 2.2 is really oriented to improve the envelope/walls inspection using the INSITER-DLL by getting feedback from real tests on other pilots further than CARTIF-3. Finally use case 2.3 will be fully deployed according to the following testing planning.

Use case	M36 Nov 17	M37 Dec 17	M38 Jan 18	M39 Feb 18	M40 Mar 18	M41 Apr 18	M42 May 18	M43 Jun 18	M44 Jul 18
Use case 2.2: Building envelope quality	Providing the latest version of the INSITER-DLL	Testing the INSITER-DLL in other pilots	Testing the INSITER-DLL in other pilots	Testing the INSITER-DLL in other pilots	Testing the INSITER-DLL in other pilots	Optimization of the INSITER-DLL	Optimization of the INSITER-DLL	Integration of the INSITER-DLL in the INSITER toolkit	
Use case 2.3: Commissioning of the solar thermal system	Data monitoring of the performance of the solar thermal system (commissioning and post-commissioning)	Data monitoring of the performance of the solar thermal system (commissioning and post-commissioning)	Data monitoring of the performance of the solar thermal system (commissioning and post-commissioning)	Data monitoring of the performance of the solar thermal system (commissioning and post-commissioning)	Data monitoring of the performance of the solar thermal system (commissioning and post-commissioning)				
				Methodology and guidelines from the T1.3 about commissioning of solar thermal	Laser scan and thermography of the key elements of solar thermal systems	Data gathering from the solar thermal equipment	KPI calculation	Final checks and extraction of conclusions	

Table 38: testing overview

The development of the use cases related to CARTIF-3 according to the 8-step INSITER methodology is as follows:

INSITER 8-Step Methodology	Application for the CARTIF-3 building
STEP 1 mapping	• Obtaining the point cloud of the areas of interest (geometry and reflectivity). • Registration of thermographic/sonic images of agreed areas.
STEP 2 checking of ordered components	• Check specifications and visual inspection. • Accept/Reject panel system according to invoiced (before installation).
STEP 3 BIM for on-site construction	• Updating the BIM model for on-site use: - The final BIM model to be suitable mainly for self-inspection , continuously updated incorporating available 2D and 3D drawings, GPS/GIS data and enhanced by the 2D imaging mapping; - The BIM model is compatible with the databases of the involved stakeholders; - The BIM model is in an interoperable RVT/IFC format and compatible with the INSITER software tools;
STEP 4 BIM-based AR	n.a.
STEP 5 clash detection	Clash detection analysis is executed to get a really useful BIM model.
STEP 6 self-instruction	n.a.

STEP 7 self-inspection	• Analysis of the quality of the outer envelope. • Humidity detection in the HVAC system inside the building. • Identification of HVAC components through point clouds. • Inspection (at delivery) of critical elements of the solar thermal system. • Continuous monitoring analysis of data to evaluate the efficiency of solar thermal system.
STEP 8 final check	• Checking the performance of the building according to the as-built situation.

Table 39: development of use cases according to 8-step INSITER methodology

6.3 Real measurement values / demonstration results from each use case

6.3.1 Introduction and objectives

Purpose of the demonstration and target group

As stated before, the CARTIF-3 demonstration building is oriented to maintenance, operation and renovation stages of the building life-cycle. Therefore, its main purpose is to provide the feedback and lessons learnt from an already-built building to the 8-step INSITER methodology. Although this 8-step methodology finishes at building delivery time, the maintenance, operation and renovation processes are very important in the building life-cycle and it also provides an added-value to the project results. Table 40 summarises how the demonstration building contributes to the 8-step methodology through the demonstration cases.

Step	Description	CARTIF-3 contribution
Step 1: Mapping	Mapping actual technical conditions of the site and building and capture the requirements	Building pathologies of the already-existing building
Step 2: Checking of ordered components	Self-inspection at procurement, production and delivery of prefab components	Not applicable
Step 3: BIM for on-site construction	Modelling of the [existing] building, site and surroundings in Building Information Model (BIM)	BIM model of the CARTIF-3 building including facilities
Step 4: BIM-based Augmented Reality	Generating and deploying BIM-based Augmented Reality (AR) for self-instruction and self-inspection	AR is not applied, but inspection based on 3D laser scanning and 2D imaging, whose combination serves to create BIM models as a basis for AR/VR
Step 5: Clash detection	Virtual validation of quality and performance by BIM Model Checking and Clash Detection	Clash detection in contrast to the BIM model (D4.4)
Step 6: Self-instruction	Self-instruction during preparation and execution of construction site and logistics	Theoretical solar thermal installation instruction delivered in T1.3
Step 7: Self-inspection	Self-inspection during construction / refurbishment / maintenance process	Self-inspection of building components and solar thermal installation
Step 8: Final check	Self-inspection and self-instruction during pre-commissioning, commissioning and project delivery	Use case dedicated to the commissioning stage (solar thermal)

Table 40: CARTIF-3 contribution to the 8-step INSITER methodology

This way allows deploying and testing some of the tools that are developed under INSITER methodology for self-inspection and self-instruction focused on BIM. Besides, it provides an additional case where the tools are applicable and usable under the scope of the 8-step methodology. To this end, a specific methodology has been applied (Fig. 137).

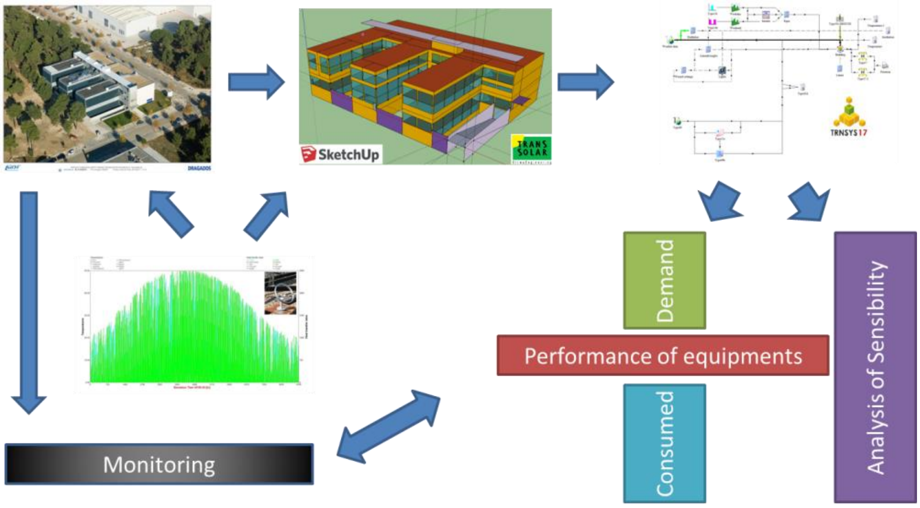


Figure 137: CARTIF-3 demonstration methodology

Basically, the methodology starts with the existing information of the building in order to check the pathologies and the requirements for the renovation project (step 1). Once they are detected, next step is to create the 3D BIM model with the elements that are necessary for the maintenance, operation and renovation (step 3). Within the BIM, the renovation solutions may be included, which, when simulated, provide data about the expected final performance or energy demand. Also, the energy demand of the building as-it-is is obtained from the hardware equipment (thermography, laser scanner) and software (monitoring systems) that provides valuable information such as real energy consumed (step 4). These tools are also applicable after the renovation in order to check and validate the solutions (step 7). Furthermore, initial indicators are necessary for the final approval during commissioning phase (step 8). However, to assure the accuracy of the results, the quality of the BIM needs to be ensured through model validation and clash detection patterns (step 5). Within the demonstration CARTIF-3 building, several stakeholders should be involved as target group:

- Architects as designers and BIM modelers for the renovation strategies.
- Engineers for the self-inspection and self-instruction methods.
- End-users which are finally affected by the comfort conditions.
- Energy experts in terms of renewable sources integration.

Contribution of partners

- Responsible of demonstration work package leader: 3L
- Responsible for CARTIF-3 demonstration: CARTIF
- Responsible for BIM-modelling: CARTIF
- Responsible for clash detection: HVC
- Responsible for thermal measurement procedures: UNIVPM
- Responsible for hardware equipment: CARTIF
- Responsible for monitoring: CARTIF
- Responsible for the software tools integration: DEMO

Description of the demonstration building

CARTIF-3 is an existing prefab nearly zero energy research building (nZEB) located in Boecillo, Valladolid (Spain), which was built by DRAGADOS. Its main use is real scale chemical/industrial prototypes testing and offices. It consists of 4.075 m^2 of floor space for CARTIF Technology Centre research activities: one quarter for offices and three quarters for the industrial activities. Figure 138 illustrates the aspect of the building.

Figure 138: CARTIF-3 building

The field demonstrate on of the building is focused on the maintenance and renovation scenarios. Although maintenance and operation are not part of the INSITER steps, the available information of the building (monitoring, experiences, etc.) gives support to the decision-making and the improvement of the INSITER methodology. For this purpose, the main demonstration activities have been aligned with the pathologies detected, as summarised in Tabel 41. The corresponding use cases were established on them, pointing the detection of air tightness (upon geometrical deviations), moisture detection and coverage (upon reflectivity index analysis) and efficiency of the renewable energy integration (upon thermal energy performance). Some of these pathologies are already solved, which include the solution as well.

Pathology	Location	Solution
Thermal bridges	Windows and doors	Not solved
Lack of insulation	Industrial façade	Increase of the insulation panels in the north façade
Bad plumbing	Distribution circuit	Modification of the pipes and sensors
Low comfort level	Offices	Integration of control systems and monitoring
Low temperatures	Industrial space	Not solved
Panels connectivity	Thermal envelope	Not solved
Bad installation (flow)	Distribution circuit	Re-size distribution systems to ensure comfort
Overheating in summer	Cooling system	Application of free-cooling to reduce temperatures

Table 41: Pathologies of the CARTIF-3 building

In contrast to the aforementioned pathologies, it should be noted this is an nZEB with energy consumption below 60 kWh/m^2·yr. Furthermore, the insulation levels deal with low thermal conductivities, with U-value = 0.452 W/m^{2}K in the south façade and 0.468 W/m^{2}K in the north. However, it was detected some deviations with respect to the designed case that conclude in air leakages, thermal bridges and moisture reducing the energy efficiency. As well, the performance of the renewable energies is also important to contribute as specified during the design and construction phases. For that end, the BIM model was constructed in order to overlay the scanner images in the designed BIM model and, thus compare both cases to extract conclusions (Figure 139).

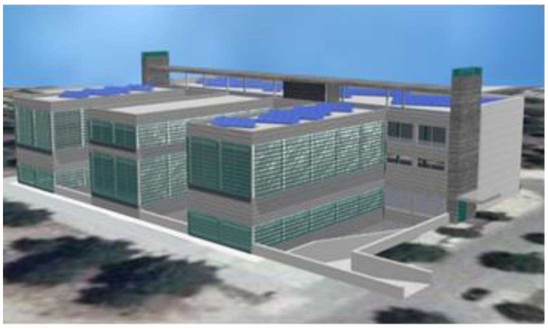
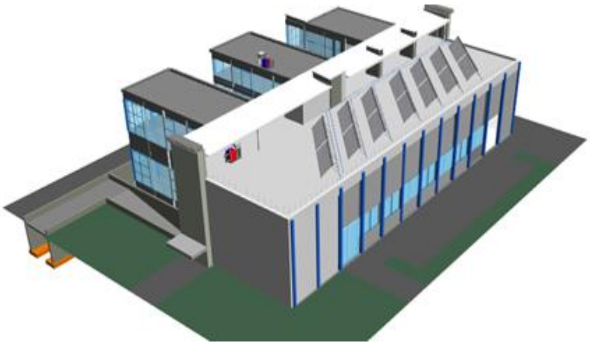



Figure 139: CARTIF-3 building 3D view and BIM model

Description of set of demonstrations

The demonstration in the CARTIF-3 building mainly aims to provide a decision-making mechanism for the quality assurance of the thermal energy characteristics; that is the application of self-inspection methods that could support the decision about the energy conservation measures according to detected pathologies. In this way, a set of key indicators are defined in order to give quantitative impact of the effects of anomalies. The decision is always made by the experts in contrast to the numerical values, while the INSITER tools provide self-inspection procedures.

More specifically, the CARTIF-3 demo site aims to three main goals:

- Detection of geometrical deviations in contrast to the design, which are translated into thermal bridges and air leakages, producing thermal losses and, therefore, lower energy efficiency. This is related to the quality of the construction works, where errors are easily identified and, thus, the quality is improved, as well as the thermal features by better envelope features.
- Detection of moisture impact and coverage. Moisture is synonym of low comfort levels due to the increase of relative humidity values. Hence, the early detection of moisture, both at envelope and HVAC system levels, is pivotal for comfort insurance. Moreover, moisture in HVAC distribution circuits is usually associated to water leaks, incrementing the energy resources for complying with the energy demand.

Assurance of the HVAC efficiency for the renewable energy sources by means of applying a commissioning procedure to check quality of the installation and fulfilment of the designed renewable contribution by initial operation indicators.

The main demonstrations carried out in the CARTIF-3 building are focused on:

1) Checking the measured values of building components (self-inspection at component level)
2) Assessing the building envelope quality (self-inspection at building level) and
3) Commissioning of solar thermal systems related to maintenance demands (self-inspection and self-instruction for renewable energy components).

The main façade is south oriented, with almost the entire cover-up and the entire south-west side closed with a glass wall that improves solar gain and a blind with oriented louvers, fixed to optimize the daylight use, avoiding glare. But, it provokes thermal bridges owing to blind deviations (Figure 140 left) because they were not planned during design.

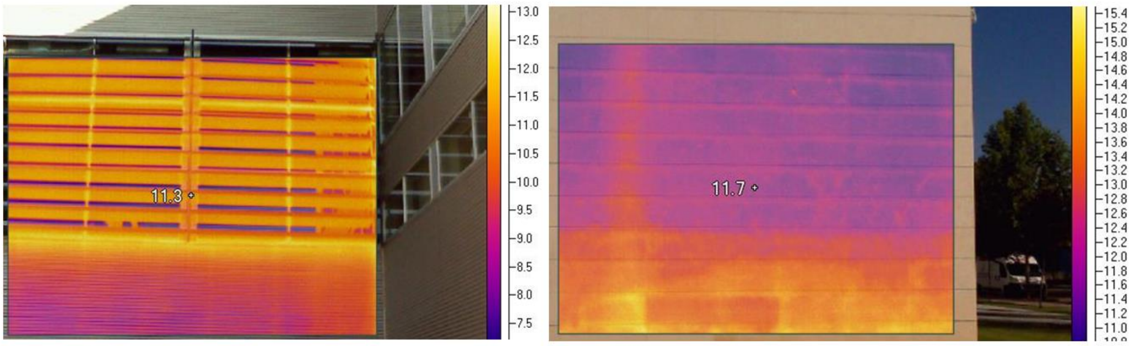


Figure 140: Thermal performance of the building

On the other hand, north façade is dedicated to industrial areas where heating demands are less restrictive due to comfort constraints. Nevertheless, as observed in Figure 140 right the insulation is not homogeneous across the façade, generating lower thermal energy efficiency than as expected. It should be noted that the envelope has been designed to minimize thermal energy such as heating and cooling and light electrical demand through a special concept (glass wall and louvers blinds) that allows an important use of daylight with high solar gain and reduces thermal requirements and a high insulation in the different elements of the envelope.

As described across this document, the demonstration is carried out through use cases to cover the specific objectives. These use cases are described below.

6.3.2 Use case 1: Check and approval of measured values (steps 3, 5 and 7 of the INSITER methodology)

3D imaging sensors, such as laser scanners, are being used not only to create CAD/BIM models of the as-built conditions of prefab made buildings, but also for quality assurance comparing the current 3D data with the available CAD/BIM geometry to identify geometrical errors (deviation analysis). Then, 3D point clouds and laser scanning derived models (even geo-located) can improve building projects by analysing clashes between newly designed elements and existing conditions or by evaluating the current situation prior to refurbishment. The accurateness of dimensions obtained by laser scanning can also help to improve planning by providing exact measurements for insertion and removal of prefab components, minimizing waste and changes in the field. Qualitative (images and 3D representations) and quantitative (numerical statistics) analysis of the geometric deviations between a design (CAD/BIM model) and the point cloud corresponding to the real situation are readily provided for construction and refurbishment purposes. In this case, the deviations are analysed through 7 check-points as highlighted in Figure 141. More details about the specific steps of the use case are included in Table 42.

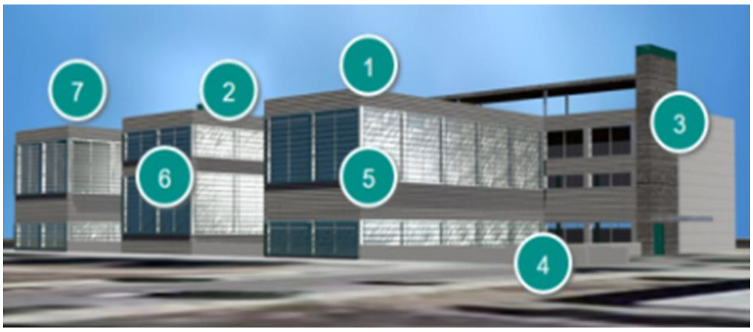


Figure 141: Deviation check-points

	Description	responsible partner	additional input	Time schedule	tools to be used in site testing
Step 1	Create CAD/BIM Model	CARTIF, construction or architectural company	n.a.	CAD done / BIM almost finished version	CAD / IFC viewer
Step 2	Upload CAD/BIM to server	HVC	n.a.	CAD done / BIM preliminary version	n.a.
Step 3	On-site 3D data acquisition (laser scanning or photo scanning)	CARTIF, surveying company	n.a.	done	Laser scanner / Hi-tech photocamera / Point cloud viewer
Step 4	3D processing, editing and registering: useful point clouds obtention & accuracy assessment (by feature modelling)	CARTIF, surveying company	n.a.	done	
Step 5	Upload relevant point cloud/s to server	CARTIF, HVC, building owner/manager		done	INSITER guidelines
Step 6	Fixing tolerance thresholds: positive (Hi+; Lo+) and negative levels of (Hi-; Lo-)	Construction or architectural company	owner / manager feedback	done	
Step 7	Computing deviations in the nominal -shortest-direction between the reference model (CAD/BIM) and the data model (point cloud)	CARTIF, surveying company	SW tool supporting reverse-engineering workflows	done	Reverse-engineering tool viewer
Step 8	Check, report & analysis of results: current status of the building made of prefab components	CARTIF, 3L, DEMO	owner / manager feedback		INSITER software tool

Table 42: Check and approval of measured values use case, activity list, steps 3, 5, 7 of INSITER 8-step methodology

6.3.3 Use case 2: Building envelope quality (step 3 and 7 of the INSITER methodology)

The process to combine 2D imaging (e.g. infrared thermography) with 3D data is described, just making it usable into BIM through a dedicated plug-in called INSITER-DLL. To help the self-inspection procedure, the tailored INSITER-DLL plug-in allows combining 2D & 3D relevant information (geometry, colour, reflectivity, thermography, etc.) to be managed into REVIT as BIM representative tool through point clouds with PLY format (well-known structure to describe an object as a collection of vertices, faces and other elements, along with properties such as colour and normal direction).

6.3.4 Use case 3: Commissioning of solar thermal system (step 7 and 8 of the INSITER methodology)

During the lifespan of the solar thermal systems there are faults, underperformance, wrong operation conditions, and unexpected shutdowns of the installation. Thus, the target of this use case is to avoid as much as possible those problems and try to improve the installation performance in relation to the foreseen quality. Two aspects need to be gathered regarding solar thermal systems installed in energy-efficient buildings made from prefabricated panels:

- Verify if the components of the solar system (solar collectors, pumps, plumbing, heat exchanger, thermal storage and controllers) are in accordance with the purchase requirements, then the guidelines for the proper installation of the solar system through VR/AR.
- Surveillance the performance of the solar thermal system during its life-spam taking in to account the specifically related thresholds and KPI.

	Description	responsible partner	additional input	Time schedule	tools to be used in site testing
Step 1	3D laser scanning / photo-scanning of representative elements / areas /envelope of EE buildings made of prefab modules: geometry (XYZ coordinates); colour (RGB coordinates: real appearance); reflectance (L index: materials and humidity).	CARTIF, surveying company	owner / manager feedback	done	Laser scanner / Hi-tech photocamera / Point cloud viewer
Step 2	Processing the L index according to a tailored algorithm for moisture checking	CARTIF	n.a.	done	n.a.
Step 3	3D data processing, editing and registering: useful point clouds	CARTIF, surveying company	n.a.	done	Reverse-engineering tool viewer
Step 4	Upload relevant point cloud/s to server	CARTIF, HVC, building owner/manager		done	INSITER guidelines
Step 5	Thermography imaging where needed within the scanned area/s (to assess heat gain/loss and thermal bridges)	CARTIF, UNIVPM, energy engineering or consultant	owner / manager feedback	done	Thermal camera
Step 6	Acoustic imaging where needed within the scanned area/s (to assess comfort conditions - noise is wasted energy-)	SIEMENS, construction engineering or consultant	owner / manager feedback		Sound brush
Step 7	Mapping images on 3D point clouds in a raster-based process	CARTIF, SIEMENS		done	MeshLab free open source tool or eq.
Step 8	Exporting the previous enriched 2D/3D mapping as PLY. As many PLY files as needed are created (a single PLY file per mapping)	CARTIF, SIEMENS		done	MeshLab free open source tool or eq.
Step 9	Using the specially tailored INSITER-DLL plug-in to precisely displaying the PLY files by layers into REVIT (a specific toolbar is created).	CARTIF, HVC, DEMO, 3L, construction engineering or consultant		done	REVIT & INSITER-DLL plug-in
Step 10	Using of PLY files to aid drawing BIM parametrical features to be taken into account as part of a REVIT project	CARTIF, HVC, DEMO, 3L, construction engineering or consultant			REVIT & INSITER-DLL plug-in
Step 11	Upload the resulting unique working project (RVT/RFA/IFC converted files) to server	CARTIF, HVC, building owner/manager		done	INSITER guidelines
Step 12	Check, report & analysis of building envelope quality	CARTIF, 3L, DEMO	owner / manager feedback		INSITER software tool

Table 43: Building envelope quality use case, step 3 and 7 of the INSITER 8-step methodology

This use case is split in several steps as represented in Table 44. It should be noted that the solar thermal system in CARTIF-3 building already exists; therefore, some of the steps are not feasible.

	Description	responsible partner	additional input	time schedule	tools to be used in site testing
PREPARATION OF INFORMATION INTO THE INSITER TOOL					
Step 1	Include solar thermal system into BIM model	CARTIF		done	
Step 2	Provide and upload technical information (2D/3D installation schemes, panel specs, etc.) and self-instruction guidelines in INSITER server	CARTIF	technical specifications from manufacturer/ provider	done	
Step 3	Provide bar/QR code linked to panel information in INSITER server	CARTIF	technical specifications from manufacturer/ provider	n.a. *	
VERIFICATION					
Step 3	Scan bar/QR code	CARTIF (responsible for reception)	-	n.a. *	bar/QR code scanner
Step 4	Check specifications and visual inspection	CARTIF (responsible for reception), installer	-	n.a. *	
Step 5	Accept/Reject panel system according to invoiced (before installation)	CARTIF (responsible for reception)	-	n.a. *	INSITER software tool
INSTALLATION: SELF-INSTRUCTION AND COMMISSIONING					
Step 6	Check of glycol/water mixture concentration for antifreeze protection	Installer	-	n.a. *	INSITER guidelines
Step 7	Filling process according to INSITER self-instruction guidelines	Installer	-	n.a. *	INSITER guidelines
INSTALLATION: SELF-INSPECTION DURING PRE-COMMISSIONING					
Step 8	Geometrical tests based on 3D laser scanner	Installer	-	On demand	INSITER guidelines
Step 9	Thermal tests based on thermography	Installer	-	done	INSITER guidelines
Step 10	Pressure tests	Installer	-	n.a. *	INSITER guidelines
Step 11	Accept/Reject panel system installation according to INSITER guidelines	CARTIF (responsible for reception)		done	INSITER software tool
SURVEILLANCE AND CONTINUOUS COMMISSIONING: SELF-INSPECTION DURING MAINTENANCE					
Step 12	Definition of indicators and tolerance thresholds for critical operation variables	CARTIF	owner / manager feedback	done	
Step 13	Prioritization of alarms	CARTIF	-	done	

Step 14	Implementation of indicators (KPIs) and alarm rules into the INSITER tool	CARTIF, DEMO	-	done	
Step 15	Making monitoring data available in the INSITER tool	CARTIF, DEMO	-	done	Existing monitoring, INSITER software tool
Step 16	Computing KPIs and check deviations between actual and desired operation	CARTIF, 3L, DEMO	owner / manager feedback	done	INSITER software tool
Step 17	Report & analysis of results: current status of the solar panel system	CARTIF, 3L	owner / manager feedback	done	INSITER software tool
*	*Solar panels in CARTIF-3 demo building already exist and are installed.*				

Table 44: Solar thermal commissioning use case, activity list, steps 7 and 8 of INSITER 8-step methodology

Connection with other work packages

The main connections are not only in hardware but also in software:

In terms of hardware: linking to *WP2-T2.2: Measuring, imaging and diagnostic systems and equipment*, focused on self-inspection:

- Usability of 3D laser scanning for dimensional control, both at prefab panel level and the entire building envelope level.
- Dealing with the reflectivity index provided by a laser scanner for the differentiation of materials and moisture content according to these materials.
- Using point clouds provided by a laser scanner for parametric modelling of HVAC / MEP elements.

In terms of software:

- Linking to WP2-T2.2: Measuring, imaging and diagnostic systems and equipment, for self-inspection purposes:
  - Providing the procedure and related tool to combine high-quality 3D digital surveys together with 2D imaging and make them usable into a well-known BIM environment to represent the current state of the existing fabric, but also the exploration and multifaceted analysis of maintenance related interventions.
  - Going one step further, combining these 2D/3D overlapped elements of information with state of the art 3D spatial positioning systems for indoor/outdoor alignment & referencing (using geometrical, fiducial, GPS, IPS data) or just to be included into GIS environments. The connection to AR/VR applications is also pointed out.
- Linking to WP3-T3.1/T3.2: Applications for planning, cost monitoring and quality & energy assessments, focused on self-inspection and self-instruction:
  - Usability of monitored data for operation checks in terms of HVAC elements according to specifications and data-sheets.
  - Calculation of indicators to obtain energy performance of HVAC systems.
  - Combination of static, semi-static and dynamic data to perform quality checks (malfunctioning).

INSITER Research & Technical Development results used in the demonstration

Within the main research and technical developments, next bullets give an overview of the developments that have been carried out to overcome the requirements of the use cases.

Development of BIM-model (step 3 of the INSITER methodology)

The principle of the INSITER project is that the BIM-model is the core of all information. Therefore, a BIM model is necessary to apply the different tools developed along the project. In this case, the creation of the BIM model for the CARTIF-3 building relied on the 2D images and drawings from the original project in combination with dimensions taken from the partial point cloud of the building by laser scanning. As mentioned before, the model is created with the aim of applying self-inspection techniques at component level. Therefore, the model is split into spaces, as illustrated in 142: external walls, solar thermal system, etc. in order to apply the defined use cases.

Figure 142: external walls, solar thermal system, etc. In order to apply the defined use cases

BIM validation and clash detection (step 5 of the INSITER methodology)

According to the step 5 of the INSITER methodology the BIM model should be validated in order to avoid clashes or interference between elements. Hence, a procedure to analyse the most common interferences has been deployed. In this sense, the floors and structural foundations have been considered, as well as curtain panels, curtain walls, structural columns and walls. Figure 142 shows the interference checks that were detected in the initial BIM model, which required modifications to properly validate the BIM model before the implementation of the INSITER tools.

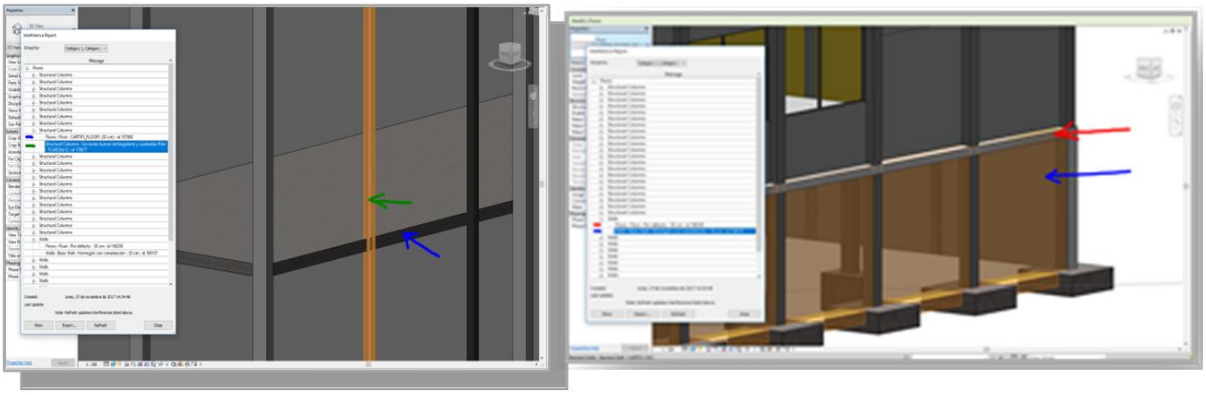


Figure 143: Interference check for CARTIF-3 model

Apart from the graphical results, a report is generated with all the results before the final validation. Basically, it summarises all the identified interference points and the results from the interference checks. Figure 144 shows the example of the interference report that has been generated for the CARTIF-3 demonstrator.

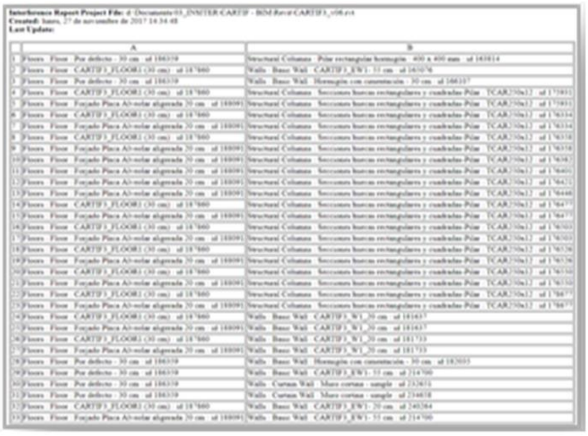


Figure 144: Interference check report

Moisture detection (step 7 of the INSITER methodology)

By 3D laser surveying, useful digital point clouds, including geometrical, colour and reflectivity information is readily obtained, not only to register the current status of the building, but also to reveal the moisture content and extension according to type of material.

Once the corresponding point clouds are obtained, the raw reflectivity value has to be corrected mainly according to: (1) the distance between the scanner and the digitized surface; (2) the angle between the surface normal and the laser incidence direction at the current point of the surface. Then a refined value is obtained, useful for moisture detection and assessment (Figure 145). These refined point clouds can be registered in a common framework afterwards.

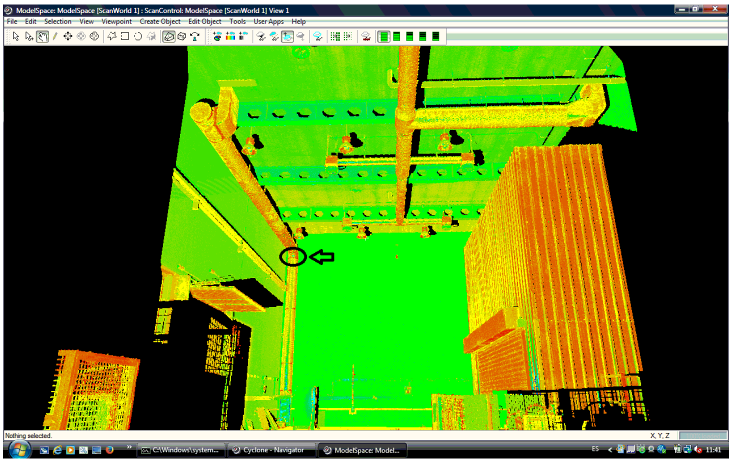


Figure 145: Detection of a small steam leak in the elbow of a HVAC system pipe from the CARTIF-3 workshop

Connecting 3D surveying and 2D imaging instruments to BIM (step 7 of the INSITER methodology)

A plug-in for REVIT to interconnect the different surveying and imaging instruments to BIM has been specifically developed. Suitable digital information sources are 3D point clouds and 2D images. The latest version available of the method and related mentioned plug in (INSITER-DLL) is described in section 3 of *D2.4: Integrated site and indoor positioning systems for measurement and diagnostic instruments*. An example is shown in Figure 146.

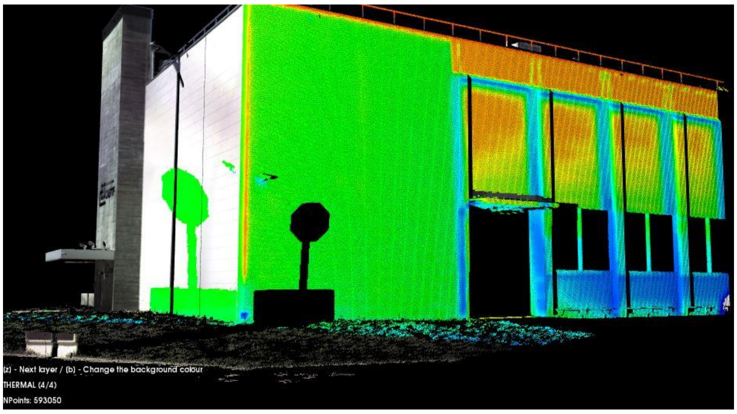


Figure 146: Point cloud with thermographic overlay usable into REVIT

Commissioning of the solar thermal system (step 8)

The commissioning phase, before delivery, is crucial to verify if the performance of the building and MEP/HVAC elements is the expected one according to technical specifications. For the case of the building envelope, commissioning is usually based on tests like blower door test, thermography, etc. Nevertheless, the commissioning of the HVAC facilities requires data registering & analysis. Apart from the usual visual check about the proper installation, there is no way to assure the distribution elements are operating as expected (covering the demand) without information upon data. BIM data do not provide all the necessary information, but dynamic data should be integrated. Dynamic data refer to changing information that is periodically updated. The information contained in the BIM is related to static data. Hence, a methodology for the integration of static and dynamic data in the building context has been implemented in order to map the BIM elements (in this case, the solar thermal system) with real-time measurements that help to validate the CARTIF-3's HVAC system installation.

Basically, it relies on a database linked to the BIM model, which contains the physical elements. The BIM model makes use of global IDs that are unique identifiers for each of these elements. In this sense, the dynamic database makes also use of these identifiers to associate the sensor and the virtual component. For instance, Figure 147 left shows four sensors measuring air temperature and its related identifier (as modelled in IFC within the BIM model). Similar approach is applied for the KPIs (Figure 147 right).

	globalid [PK] character varying (50)	name character varying (100)	sensortype integer	relatedelement character varying (50)
1	0I10GHZQ9CxfLGWEiu0uqJ	LOGS-01_SENSOR_SALAS-C3_ZONA_PARED-Temp_Amb_Z...	63	0u9B7y78DDC9qjKE8P8lq3
2	0I10GHZQ9CxfLGWEiu0v3e	LOGS-01_SENSOR_SALAS-C2_ZONA_VENTANA-Temp_Am...	51	0u9B7y78DDC9qjKE8P8lqv
3	0I10GHZQ9CxfLGWEiu0v9q	LOGS-01_SENSOR_SALAS-C1_ZONA_PARED-Temp_Amb_Z...	63	0u9B7y78DDC9qjKE8P8lq1
4	0I10GHZQ9CxfLGWEiu0vCl	LOGS-01_SENSOR_SALAS-C2_ZONA_VENTANA-Temp_Am...	52	0u9B7y78DDC9qjKE8P8lqv

	kpi_id [PK] character varying (50)	name character varying (100)	description character varying (300)	relatedbuilding character varying (50)
1	CIII_CO2_AHU	CIII_CO2_AHU	CIII_CO2_AHU	0s2WvaxHHCXf$Iz6eTSrB8
2	CIII_CO2_AUX	CIII_CO2_AUX	CIII_CO2_AUX	0s2WvaxHHCXf$Iz6eTSrB8
3	CIII_CO2_BB	CIII_CO2_BB	CIII_CO2_BB	0s2WvaxHHCXf$Iz6eTSrB8
4	CIII_CO2_BIO	CIII_CO2_BIO	CIII_CO2_BIO	0s2WvaxHHCXf$Iz6eTSrB8

Figure 147: Mapping tables between static and dynamic elements

For this purpose, the dynamic database has been modelled following the IFC standard and its relationships, as illustrated in Figure 148. In this way, a replicated sub-schema of the BIM model is available, whose novelty is the inclusion of the also standard TimeSeries object that represents dynamic data-sets (i.e. data measurements).

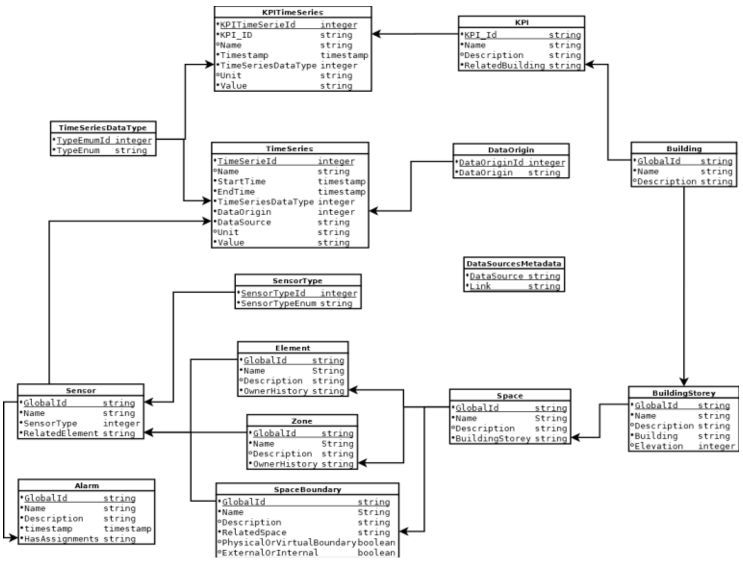


Figure 148: IFC-based dynamic database

With this information, it is easily linked a static element with its dynamic information. The example for one sensor is depicted in Figure 149. On the left side, the sensor within the BIM model is selected, where its properties may be also observed (including the IFC-ID for its identification). Once this parameter is obtained, through the database-dll plugin, the dynamic information associated to the elements can be extracted, as illustrated on the right side of Figure 149.

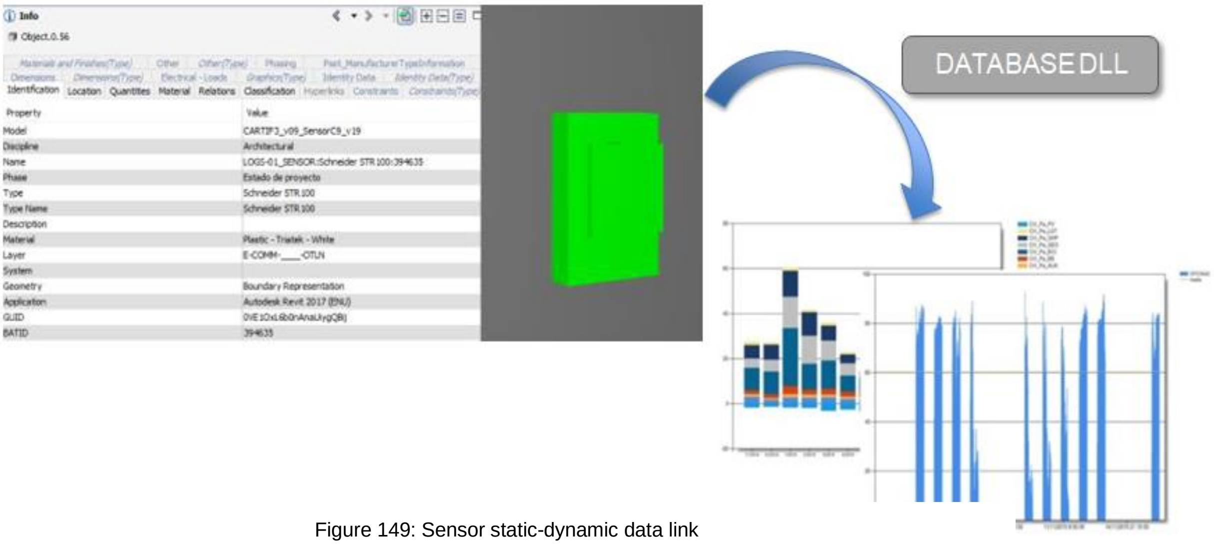


Figure 149: Sensor static-dynamic data link

To wrap up, having this information available, a set of KPIs can be calculated according to the data-sheets and the design of the HVAC elements and, thus, validate the installation of the HVAC system before delivery.

Key Performance Indicators / metrics for measuring impacts

As stated before, the ultimate goal of the use cases is to determine the impact of several common errors during the building life cycle. One of the biggest INSITER challenges is to measure the effects that the errors cause into the energy efficiency. Thus, a set of KPIs and thresholds for each use case are defined, calculated and analysed with the aim of determining the energy efficiency impact in the building. In this way, the objective is not to make a decision, but support the stakeholder’s decision objectively.

The currently proposed KPIs and thresholds are founded on their usability for construction companies and workers. They could be either indirect (there is no model to set up a direct relationship between the indicator and the effectiveness of INSITER techniques/tools linked to energy performance & efficiency: use cases 1 and 2), or direct (use case 3).

Use case 1: Check and approval of measured values (steps 3, 5 & 7 of INSITER methodology)

The proposed KPI and related threshold are supported on the on-site results for CARTIF-3 presented in section 3.3.1 of the deliverable **D5.3: Case study elaboration, field validation protocols, and equipment calibration**. The corresponding justifications/explanations are given in notes (a), (b) and (c) of that table.

Dimensional control				
KPI	Application level	Measurement aspects	Measurement instruments	Measurement parameters [Units]
Design to construction consistency / Current to previous status construction consistency	Doors and windows [a]	Geometrical deviations	3D laser scanner	Deviations tolerance [m][b]
Threshold	Action needed (red)	Action possibly needed (yellow)	No Action needed (green)	
3 x Std[c]	≥ 2 x Threshold	≥ Threshold	< Threshold	

(a) Constructive elements where the greatest energy losses may occur.
(b) Millimetres are typically used.
(c) Standard deviation by modelled accuracy (plane featuring). Example: 1.2 mm for CARTIF-3 building at envelope level.

Tabel 45: Dimensional control KPI

Use case 2: Building envelope quality (step 3 and 7 of the INSITER methodology)

Two KPIs are proposed for the important case of moisture detection and assessment: KPI (1) in reference to the information provided by the corrected reflectivity index (as one of the layers of the INSITER-DLL) for early detection of surface moisture and KPI (2), which accounts for the extent of moisture detected (Tabel.46a: *Moisture* detection and assessment KPI

These KPIs and related thresholds are supported on the on-site results for CARTIF-3 presented in section 3.3.2 of the deliverable **D5.3: Case study elaboration, field validation protocols, and equipment calibration**.

Proper justifications/explanations are given in the corresponding notes (d) to (g) of these tables.

Moisture detection and assessment				
KPI (1)	Application level	Measurement aspects	Measurement instruments	Measurement parameters [Units]
Moisture (early) detection	Envelope area (inside and/or outside) / MEP-HVAC element	Surface moisture content	3D laser scanner	Index of reflectivity correlated to a thermo-hygrometer[d] [%]
Threshold		Action needed	Action possibly needed	No Action needed
Moisture content (MC)[e]		MC < 30%[f] or MC > 60%[f]	MC descending: value close to 30% MC ascending: value close to 60%	30% < MC < 60%

(d) The reflectivity index (quantifiable between 0 and 1) must be corrected fundamentally in distance and angle of the laser incidence with respect to the digitized zone. Once corrected, this value is matched to moisture content (quantifiable in %) for a specific material by means of a thermo-hygrometer.
(e) The higher the humidity at a given temperature, the more heat the air can hold.
(f) There is no standard or rule relating humidity to energy performance, but it does relate to values of comfort and conservation of materials, so 30% and 60% figures are pointed out.

Tabel.46a: Moisture detection and assessment KPI

Moisture detection and assessment				
KPI (2)	Application level	Measurement aspects	Measurement instruments	Measurement parameters [Units]
Moisture coverage	Envelope area (inside and/or outside) / MEP-HVAC element	Percentage of wet surface	3D laser scanner	Area affected by humidity according to KPI (1) with respect to the total area analysed [%]
Threshold		Action needed	Action possibly needed	No Action needed
Area affected by humidity (AAH)		AAH ≥ 10%[g]	AAH ≥ 5%[g]	AAH < 5%

(g) Figure based on CARTIF's experience working in close relation to construction companies.

Tab. 46b: Moisture coverage KPI

Use case 3: Commissioning of the solar thermal system (step 7 and 8)

For the case of the solar thermal system, two KPIs are necessary for the assessment of the operation conditions. Apart from the commissioning indicators that are documented in D1.6 and D1.7, table 47 and 48 summarise the two critical issues to be evaluated before the delivery. KPI (1) is related to the energy performance of the solar thermal system (exchanger), which should be limited within the designed performance. Renewable energy systems are designed for a specific energy performance. If this is not complied, then an action is needed to assure the final quality.

Commissioning of solar thermal systems				
KPI (1)	Application level	Measurement aspects	Measurement instruments	Measurement parameters [Units]
Energy performance	MEP/HVAC elements (heat exchanger, panels, tanks…)	Thermal performance	Heat-meter	Energy contribution and demand [kWh]
Threshold		Action needed	Action possibly needed	No Action needed
Normalised performance [h] of the solar thermal system (η)		$\eta < 0.75$	$0.75 \leq \eta < 0.85$	$\eta \geq 0.85$
(h) Actual operating performance over the nominal performance specified by the manufacturer.				

Tabel. 47: Energy performance KPI

Secondly, as critical element of the solar thermal system, storage should be checked so as to reduce the energy losses due to lack of insulation or other aspects. KPI (2) is focused on this issue. In this sense, on one hand, the legionella aspects must be ensured. On the other hand, energy performance taken into account to keep the stored temperature in the specific design with the aim of ensuring the energy contribution as designed.

Commissioning of solar thermal systems				
KPI (2)	Application level	Measurement aspects	Measurement instruments	Measurement parameters [Units]
Solar thermal storage	MEP/HVAC elements (storage tanks)	Storage temperature	Thermography, sensor probes	Storage temperatures [ºC]
Threshold		Action needed	Action possibly needed	No Action needed
Storage temperature of the tanks		T < 50°C or T > 90°C	50°C ≤ T < 60°C	60°C ≤ T ≤ 90°C

Tabel. 48: Solar thermal storage KPI

In terms of evaluation of these KPIs, the aforementioned techniques about dynamic data integration has been followed. Figure 150 shows an example of the data visualisation, which in fact is used for proper assessment.

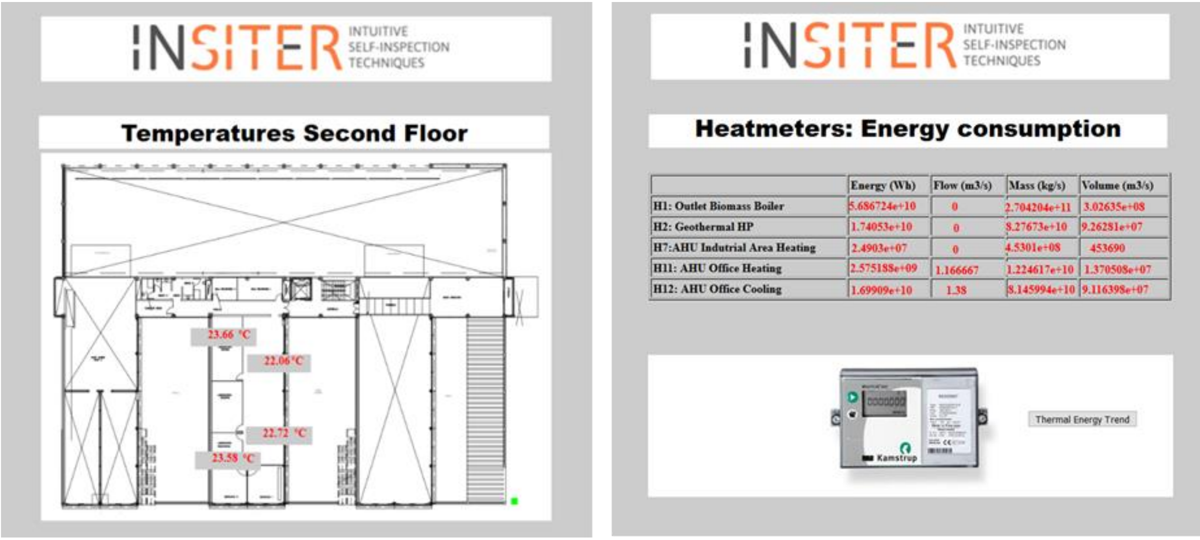


Figure 150: Visualisation of measured data

It should be also highlighted that the commissioning procedure usually takes some days with the aim of validating the proper behaviour, although it is very important to keep record of data during maintenance and operational phases of the building. The reason is the possibility of reducing the performance and energy efficiency along time. This part is out of the scope of INSITER project, although the commissioning procedure based on KPIs is also applicable during maintenance and operation.

Starting with the solar thermal system and exchanger, the first result is through the application of thermography in the solar thermal collectors to check the thermal properties of the system. It is simply visualised, rounded in green in Figure 151, there are two vacuum tubes, which do not operate. It is difficult to quantify the energy efficiency effects of this preliminary result, but, at least, it provides an overview to the stakeholders about installation errors.

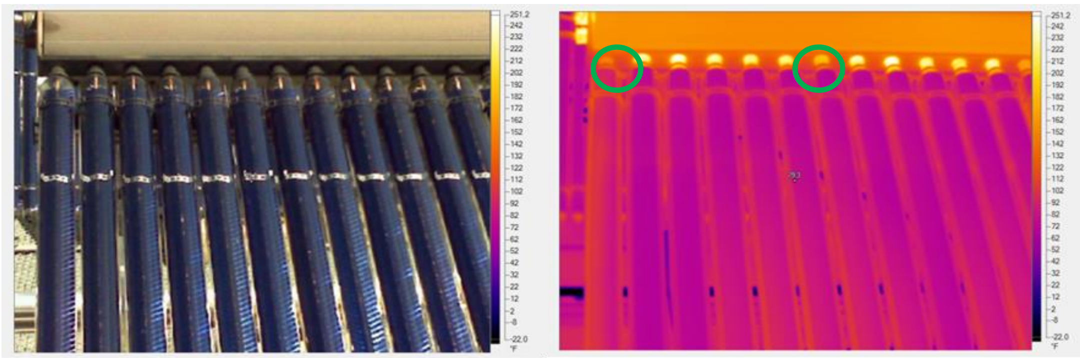


Figure 151: Thermography of the solar thermal system

Once the initial errors are detected, next is the validation with data. As stated before, a limited set of data is enough to validate the installation during the commissioning phase. In this specific case, one day (21st of June) has been used to determine the energy performance of the system. Starting with the analysis of the temperatures, Figure 152 represents the trends for the primary inlet/output temperatures (T1) and secondary circuit (T2). As observed, the working hours of the solar thermal exchanger spans from 10:00 to 20:00, as expected in summer season. Additionally, the primary circuit reduces the temperature from approximately 104°C to 96-98°C, being the difference of 6-8°C, which is exchanged to the secondary circuit, heating the water from approximately 71°C to 78-70°C.

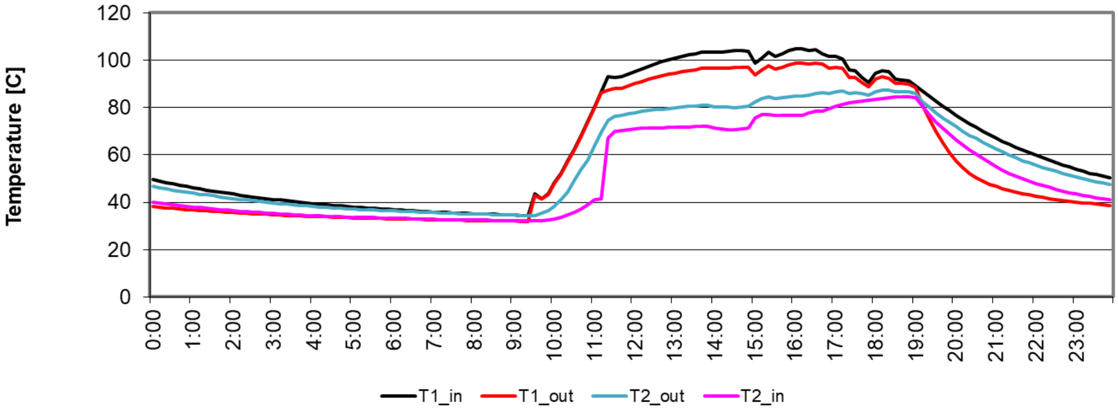


Figure 152: Solar thermal exchanger temperatures

As second data input is the power of the solar thermal system that is represented by the black lines in Figure 153. Starting with a visual inspection, the power is, as expected, generating energy during the radiation hours. Nevertheless, from this picture, the most important graphs correspond to red and blue lines (R as performance and E as effectiveness). The performance of the solar thermal exchanger is around 0.95 according to the exchanged power, which indicates only 5% of the thermal energy is lost in the thermal energy exchange process. This value is within the ranges expected taking into account the data-sheets. In the case of the effectiveness, which is the calculated real performance in the KPI (1), it is observed as its value is much lower, achieving approximately 0.29. The nominal effectiveness is 0.75, therefore the calculation of the KPI (1) is 0.39. Looking at Table 47, the value is below 0.75, hence action is needed. In the case of CARTIF-3 building, a more specific analysis was carried out to understand the low effectiveness of the solar thermal system and it was detected the pumping system was wrongly installed, reducing the water flow capacity and, therefore, being unable to supply all the water flow from solar thermal system.

With respect to the storage tanks, the procedure has been similar to the solar thermal collectors. Beginning with the thermography, Figure 153 shows a homogeneous distribution of the thermal characteristics along the storage tank, which determines the homogeneous level of insulation across it, as expected.

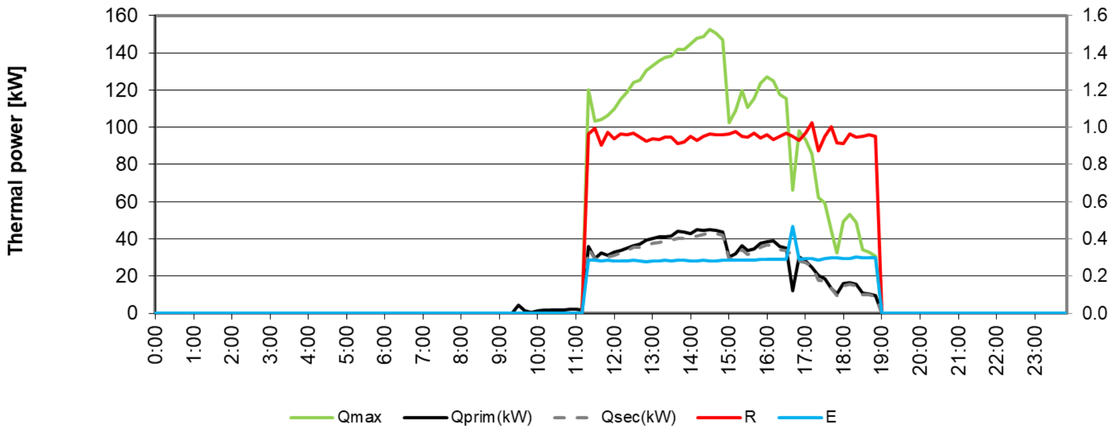


Figure 153: Thermal power and efficiency of the solar thermal

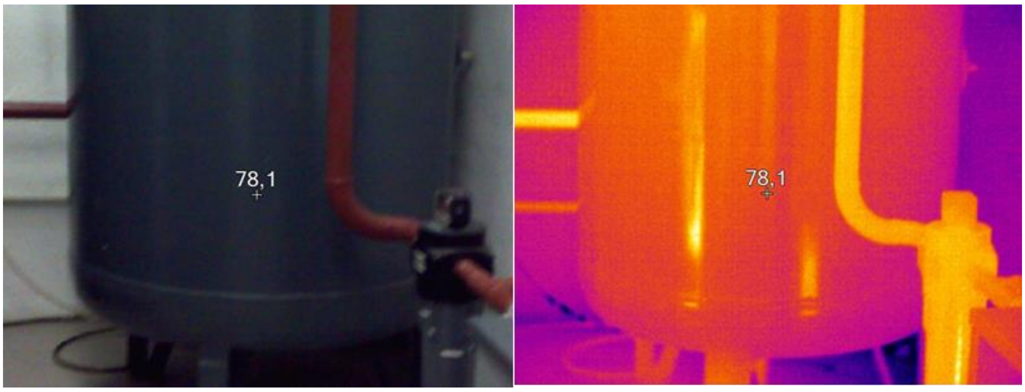


Figure 154: Thermography of the solar storage tanks

In terms of quantitative results, Figure 154 shows the temperatures for the 4 available storage tanks of the CARTIF-3 building facilities (T1, T2, T3 and T4), which are measured at top and bottom of the tanks (up and bot). As observed, their values are always between 60°C and 90°C, being compliant with the values estimated in KPI (2) for this use case. Therefore, no further action is needed, and the storage tanks are properly working. In fact, from the picture, it may be extracted the storage temperature is approximately 85°C, while, when there is consumption, their temperature is reduced up to 70°C approximately.

6.3.5 Conclusions

3D laser scanners have been proven the only devices that provide global, accurate (pinpoint) and dense data at once for self-inspection of EE buildings made of prefab components. 3D laser surveying allows measuring geometry discrepancies/deviations between newly designed elements and existing conditions or by evaluating the current situation prior to refurbishment or maintenance operations. A specific KPI for dimensional control for doors and windows is addressed. An innovative practical non-destructive moisture inspection method is ready to be used (TRL 7), based on the study of the reflectivity index. Humidity can be easily detected and displayed on the same 3D point cloud obtained when documenting such a type of buildings, usually made of homogeneous materials. In this regard, two KPIs have been established for moisture detection and assessment.

Point clouds (locally or globally referenced) can engage additional information by combining them with different types of useful 2D imaging (high-res pictures, thermographs, etc.) to be managed into REVIT (as worldwide representative tool) for BIM modelling and project planning.

Furthermore, monitoring and software tools are important means for self-inspection. Despite being mostly part of post-commissioning and operation building stages, they are influential to determine inefficiencies and malfunctioning of energy resources and, therefore, low efficiency of the energy generation systems. This sometimes deals with low energy efficiency of the building, even though the passive elements (e.g. insulation) could provide high-quality characteristics. CARTIF-3 as building in the operational phase framework provides this valuable tool upon two specific KPI for commissioning of solar thermal systems.

Compliance with Key Performance Indicators

KPIs were defined in the WP1 according to the methodologies for building components and HVAC systems, as well as the common errors. In this way, this analysis has followed the definitions from WP1 with the aim of quantitatively determining the building pathologies in contrast to the common errors database.

Compliance with stakeholder requirements

The main goal of the CARTIF3 building was to ensure the proper operation of the building during maintenance phase within the building life cycle. In this sense, some renovation activities were required to improve the energy efficiency of the building and solve the inefficiencies. Mainly, insulation levels of some of the façades were not enough and the performance of the solar thermal system was not as designed. In this sense, the involved stakeholders' requirements are according to the use cases defined at the beginning of the project, where certain pathologies were primarily determined. During this iterative process, the use of tool for self-inspection has helped to contrast the compliance of the stakeholder's requirements.

Improvement and lessons learned

Although it will be part of D5.7, initial lessons learned are focused on the necessity of these analyses of the building performance. Checks and quantitative results help to identify inefficiencies and, thus, detect building pathologies in contrast to the original design of the building. Therefore, the developed tools support the decision-making process from an objective point of view and, then, accurately, obtain the exact construction errors.

7. Real demonstration case of pre-assembly at factory site in Seville, ES

7.1 Changes compared to the original plan described in D5.3

No changes

7.2 Field validation / demonstration procedures for each use case

The demonstration project chosen will be a 150 m² modular building, designed to serve as a space for social activities for the neighbours of the area. This project allows testing the final prefab procedures. The building will probably made of three independent one storey units following the still on-going detailing process made of 5-6 modules each. Each unit will be "connected" to the other two by open air spaces. The building will include a multi-purpose main area, restrooms, warehouse, offices, etc. The final location of the building will be Seville.

The modules will be almost entirely produced in the factory of Las Cabezas de San Juan near Seville (Spain) and then shipped on-site for final assembly. The modules will be produced using low environmental impact materials, using as much as possible recycled and low cost materials. All necessary services including electricity, data, HVAC and MEP will be integrated at factory level, and final connections will be carried out on-site.

Figure 155: Infographics of the building

The plan, once the project is finally granted is to define the detailed design during the month of February 2018 and then proceed to the manufacturing of the modules. The manufacturing process will take between 7 to 9 weeks. The modules will be partially assembled at the factory to verify connections among modules and then disconnected and transported on-site by road. Once on-site, after casting the foundations (traditional concrete foundations casted on-site), the modules will be installed, connected and the building will be commissioned.

The final selection of specific use cases to test in this demonstrator includes one specific process during installation which will serve as a demonstration for self –instruction technologies developed in INSITER. Augmented reality will be used to instruct a construction worker during the installation of a window in a prefabricated panel. Besides, two other use cases have been selected, focussed on the validation of the self-inspection hardware and software developed in the project to evaluate check thermal, acoustic and air-tightness characteristics of the finalized building.

For the three use cases, the role of different INSITER partners have been identified in order to help DRAGADOS to carry out the necessary tests and generate the AR contents.

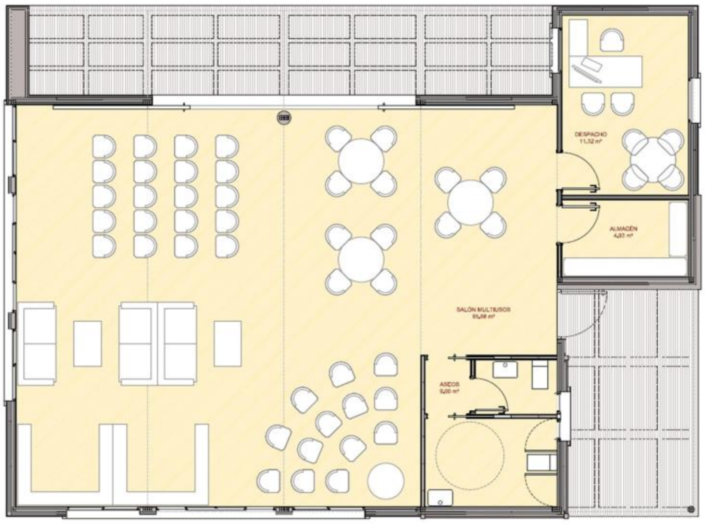


Figure 156: Floor plans view of one the three units composing the building

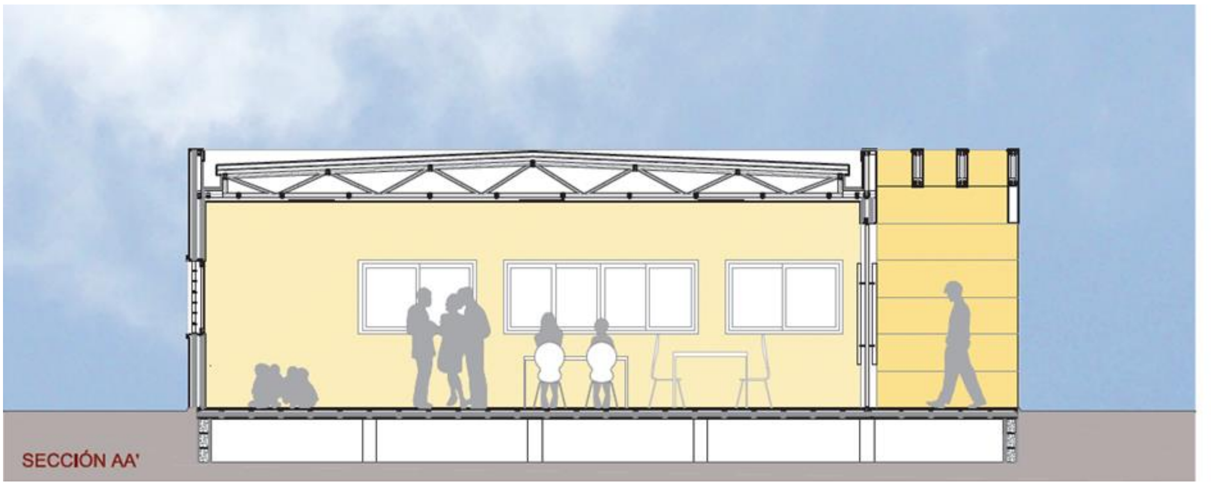


Figure 157: Elevation of the INSITER demonstrator

The prepared project “Centro Vecinal” has been put on hold by the client due to administrative problems. It seems that the project will restart on the last part of the year but that will be too late for INSITER timeframe. Alternatively, the tests carried out last year in the Prefab Factory of Seville will be reported. Those tests included the assessment of the thermal and acoustic hardware and software developed in the project, thanks to the collaboration of SIEMENS and UNIVPM. The results obtained from these tests and relevant KPIs to evaluate those results will be reported in D5.5.

TESTINGS OVERVIEW DRAGADOS MODULAR BUILDING

Use case	M36 Nov 17	M37 Dec 17	M38 Jan 18	M39 Feb 18	M40 Mar 18	M41 Apr 18	M42 May 18	M43 Jun 18	M44 Jul 18
Use case 6.1: placement of window					Off-site installation of component (window) on modules	Transportation of building to definitive location	Final checks and verification		
Use case 6.2: thermal tests					Off-site manufacture and assembly	Transportation of building to definitive location	Tests performance		
Use case 6.3: acoustic tests					Off-site manufacture and assembly	Transportation of building to definitive location	Tests performance		

Table 49: Overview testing activities

Figure 158: testing array

7.2.1 Use case 1: Window placement on prefabricated panel

Context: The first chosen use case (6.1) corresponds to the installation of a window on a prefabricated panel. This example has been since it is a procedure highly repetitive with a high impact on the thermal performance on the final building. Besides, integration between factory and external manufacturers is necessary since the window is a component which is procured, not fabricated in-house.

Validation objective: Usability of the INSITER tools in the hands of real construction workers. The operation will be recorded and compared to similar operations not using INISTER support. Feedback from workers will be collected.

The process covers the whole cycle starting on the creation of the BIM models suing the project information as starting point (steps 1 and 2).

The identification of the adequate component (window) and the right opening will follow (steps 3 and 5). This validation will be done either through QR code scanning or by verification of component specifications against project information. After that, the dimensional check of the opening and window will be carried out (step 4). AR computer vision based tracking system will be used, by applying reference markers within the BIM model and the real environment. In case of discrepancies between opening and window, the manufacturer will be informed to adapt the window.

Augmented reality content, as simple and intuitive as possible, will be used to instruct the worker. He/she will visualize the INSITER self-instruction content through either a hand-held or head-held device. This content will provide indications for the different steps to be followed to complete the window installation and associated checks (steps 7 to 10). Part of those contents will be generated using the indications on the INSITER guidelines. Construction workers carry out their activities fast, accurately and efficiently so one of the main purposes of this use case is to gather feedback for the workers on the usability of the INSITER technologies, paying special attention on the time needed to visualize the generated AR contents, the tracking accuracy of the device and the evaluation of the workers on how useful the instructions have been.

Once the component window has been installed and functionality has been verified, the module will be prepared for transportation and that implies certain verifications on the window (step 11). After modules arrive on-site (step 12), a similar verification process has to be carried out to identify any functionality loss due to damages during transport (step 13).

Use Case 6.1		**Window placement on prefab component**				
Relevant Demonstrator		Proyecto "Espacios Vecinales" Sevilla				
Responsible Insiter Parter		DRAGADOS				
Step		**Description**	**Partner**	**Additional information needed**	**Date**	**Tools to use**
Step 1		create BIM Model and AR contents	HVC	Drawings + components/ materials information Recommendations from DRA	Mar-18	IFC viewer
Step 2		upload BIM + AR procedures to server	HVC	n.a	Mar-18	n.a.
SELF-INSTRUCTION						
Step 3		Verification of building/modules façade sandwich panel	DRA	modelo BIM	Apr-18	INSITER software tool or QR scanner
Step 4		dimensional check of the wall opening	DRA	modelo BIM	Apr-18	INSITER software tool
Step 5		window reception and check	DRA	modelo BIM	Apr-18	INSITER software tool
Step 6		Upload new information to server, update BIM model	HVC		Apr-18	
Step 7		Placing and fixing the counterframe (drilling, fastening, etc.) focussing on - mechanical stability and clinging to the masonry/support, - orthogonality of the sides, - lead and level	DRA	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	Apr-18	INSITER software tool
Step 8		Glass/pane placing (if applicable)	DRA	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	Apr-18	INSITER software tool
Step 9		Sealing	DRA	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	Apr-18	INSITER software tool
Step 10		Final check and verification focussing on the following points: * proper operation of the closing mechanisms of the windows * no scratches, good finishing surface * Homogeneous sealing * Handles well fixed * proper operation of locks and other accessories (roller shutters, shutters, ...)	DRA	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	Apr-18	INSITER software tool
Step 11		Preparation for transport (shutters down, windows closed and locked, etc.)	DRA	Recommendations from Factoría de Las Cabezas staff	Apr-18	INSITER software tool
Step 12		Reception on-site	DRA	INSITER guidelines + manufacturer manual	May-18	INSITER software tool
Step 13		Final check and verification focussing on points on Step 10	DRA	INSITER guidelines + Recommendations from Factoría de Las Cabezas staff	May-18	

Table 50: data sheet use case 6.1

7.2.2 Use case 2: Thermal and air tightness evaluation of the module's façade to ensure compliance with project requirements

Context: The second chosen use case (6.2) corresponds to the measurement of the buildings thermal performance once installed on-site using INSITER hardware and software. Evaluation of thermal transmittance of the façade, identification of thermal bridges and insulation deficiencies will be carried out. Besides, airtightness will be checked.

Validation objective: The aim to check if the building complies with project requirements. Some of the tests might be requested by the client following a more standardized approach (UNE-EN 13829 or similar) so a comparison between obtained results can be done. Threshold values will be defined according to project specifications. High interaction with UNIVPM will be needed for this last part.

This use case starts once the building has been fully assembled. The process will start by the generation of any required BIM content (steps 1 and 2) and a general visual verification of the correct assembly of the building before carrying out any test (step 3). Recommendations from the INSITER guidelines will be followed to carry out the tests. The tests to be carried out can take place in any order (thermal transmittance, thermal bridges identification, infiltration meter test, etc.) (steps 4 to 6). Thermal maps will be generated and assessed by the project Quality Manager and will be used to support decision making. Besides, it will be shown to workers so they can visualize the consequences of good/bad manufacture/assembly.

If any of the project requirements in terms of energy efficiency performance are not met the necessary changes will be implemented and tests will be performed again (either using the INSITER tools or following more traditional procedures).

Figure 159: Factory testing

Use Case 6.2	**Thermal performance assessment of prefab building**				
Relevant Demonstrator	Proyecto "Espacios Vecinales" Sevilla				
Responsible Insiter Parter	DRAGADOS				

Step	Description	Partner	Additional information needed	Date	Tools to use	Comments
Step 1	Create BIM Model	HVC	Drawings + components/ materials information	Mar-18	IFC viewer	
Step 2	Upload BIM + any other information to server	HVC	n.a	Mar-18	n.a.	
Step 3	Verification of building status prior to tests (general inspection of envelope and inner partitions)	DRA	BIM model + INSITER guidelines + manufacturer's information and manuals	May-18	tablet with software INSITER	Follow (or adapt) D1.2 and D1.3 The assembly/installation manual is issued by the Manufacturer, but INSITER self-instruction actions will be presented as annotations and displayed as Augmented Reality.
Step 4	Airtightness and infiltrometer test. ("blower door test")	UPDM	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER thermal testing equipment	
Step 5	Thermography test on envelope (qualitative inspection to detect thermal bridges, insulation deficiencies, etc.)	UPDM	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER thermal testing equipment	
Step 6	Calculation of HVAC systems air flow	UPDM	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER acoustic testing equipment	
Step 8	Upload information (processed data) on server and update BIM model with new layers of information	HVC		May-18		
Step 9	Visualization of thermal and airthightness maps	DRA	tests results processed and integrated into BIM model	May-18	tablet with software INSITER	INSITER self-inspection additional layers of information (air tightness maps) will be displayed as Augmented Reality including documents with results from the measurements
Step 10	Modifications if need be	DRA	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	May-18		
Step 11	Test repetition	UPDM		May-18	INSITER thermal and acoustic testing equipment	
Step 12	Upload information on server and update BIM model with new layers of information	HVC		May-18		
Step 13	Visualization of thermal and airthightness maps	DRA	tests results processed and integrated into BIM model	May-18	tablet with software INSITER	INSITER self-inspection additional layers of information (air tightness maps) will be displayed as Augmented Reality including documents with results from the measurements

Table 51: Data sheet use case 6.2

7.2.3 Use case 3: Acoustic and air tightness evaluation of the module's façade to ensure compliance with project requirements

Context: The third chosen use case (6.3) corresponds to the measurement of the buildings acoustic performance once installed on-site using INSITER hardware and software. These measurements include evaluation of airborne noise transmittance both for the envelope and the inner spaces, impact noise test, reverberation noise test. Besides, airtightness will be checked using the INSITER hardware

Validation objective: The aim to check if the building complies with project requirements. Some of the tests are mandatory according to the Spanish Building Regulation (*Código Técnico de la Edification, CTE*) so they will have to be carried out following standard procedures. Threshold values will be defined according to project specifications. A comparison between obtained results can be done. High interaction with SIEMENS will be needed for this last part.

This use case starts as well once the building has been fully assembled. The process will start by the generation of any required BIM content (steps 1 and 2) and a general visual verification of the correct assembly of the building before carrying out any test (step 3). Recommendations from the INSITER guidelines will be followed to carry out the tests. The tests to be carried out can take place in any order (airborne noise, impact noise, reverberation time, etc., steps 4 to 7). Acoustic maps will be generated and assessed by the project Quality Manager and will be used to support decision making. Besides, it will be shown to workers so they can visualize the consequences of good/bad manufacture/assembly.

Use Case 6.3		Acoustic performance assessment of prefab building					
Relevant Demonstrator		Proyecto "Espacios Vecinales" Sevilla					
Responsible Insiter Parter		DRAGADOS					
Step		**Description**	**Partner**	**Additional information needed**	**Date**	**Tools to use**	**Comments**
Step 1		Create BIM Model	HVC	Drawings + components/ materials information	Mar-18	IFC viewer	
Step 2		Upload BIM + any other information to server	HVC	n.a	Mar-18	n.a.	
Step 3		verification of building status prior to tests	DRA	BIM model + INSITER guidelines + manufacturer's information and manuals	May-18	tablet with software INSITER	
Step 4		Airborne noise test for envelope and inner spaces	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER acoustic testing equipment	Several points (4) points per building
Step 5		Impact noise test on inner spaces	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER acoustic testing equipment	Several points (3) points per building
Step 6		Ambient noise test on inner spaces (between modules on the same building)	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER acoustic testing equipment	Several points (2) points per building
Step 7		Reverberation time test on inner spaces	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	May-18	INSITER acoustic testing equipment	Several points (2) points per building
Step 8		Upload information (processed data) on server and update BIM model with new layers of information	HVC		May-18		
Step 9		Visualization of noise maps	DRA	tests results processed and integrated into BIM model	May-18	tablet with software INSITER	INSITER self-inspection additional layers of information (acoustic maps) will be displayed as Augmented Reality including documents with results from the measurements
Step 10		Modifications to the building if necessary	DRA		May-18		
Step 11		Test repetition	SIEMENS	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	May-18	INSITER acoustic testing equipment	
Step 12		Upload information on server and update BIM model with new layers of information	HVC		May-18		
Step 13		Visualization of noise maps	DRA	tests results processed and integrated into BIM model	May-18	tablet with software INSITER	INSITER self-inspection additional layers of information (acoustic maps) will be displayed as Augmented Reality including documents with results from the measurements

Table 52: Data sheet use case 6.3

7.3 Real measurement values / demonstration results from each use case

7.3.1 Introduction and objectives

As described in D5.4, three cases were defined to be demonstrated in the factory, including thermal and air tightness evaluation and acoustic evaluation of the module's facade to ensure compliance with project requirements. The third use case, window placement on prefabricated panel using INSITER guidelines and AR technology to instruct a construction worker during the installation of a window in a prefabricated panel, has been performed September and is also used as a show case for factory workers to provide feedback on the usability of the technologies. This feedback will be reported in D5.7 Cross-case analysis and benchmarking. The other two use cases mentioned before are related to the methodologies and technologies developed within the project to evaluate the acoustic and thermal performance of the module's envelope. The final demonstrator were these tests have been carried out is one of DRAGDOS's standard 3D prefabricated modules. These modules are used to constitute most of the buildings DRAGADOS factory fabricates. Therefore, the results gathered will be easily extrapolated for future projects.

Those tests, along with suitable KPIs, are reported in this chapter.

In order to carry out these tests, DRAGADOS collaborated with UNIVPM, Fraunhofer IPA and SIEMENS.

Purpose of the demo and target group

The purpose of the demonstration is to develop the necessary methodology and evaluate the developed techniques and hardware / software tools to effectively assess the prefabricated modules' thermal and acoustic performance while they are still at the factory, before the modules are transported and assembled on-site. The results gathered after the tests are to then be compared to the pre-defined thresholds to decide whether the modules are fit for purpose or need any modifications.

The target user would be any prefabricated buildings manufacturer who wanted some to improve their off-site quality control procedures, detecting any thermal or acoustic non-compliance while still at the factory, before on-site assembly and commissioning took place.

Goals and objectives associated of the demonstration

Prefabricated buildings are generally manufactured either by pre-fabricating 3D modules which include modular buildings prefabricators who manufacture buildings made of off-site manufactured and pre-assembled 3D modules, rather than on-site assembly of 2D components to conform the buildings.

These building's thermal and acoustic performance have to be tested on-site, during the building's commissioning phase when the modules are already assembled on-site. Those on-site tests, defined by national prescriptive technical codes or standards, are the ones which will be used as validation of the building's compliance with the regulations in place and the project's requirements. If any modification has to be made to the building as a result of a non-compliance in any of those tests, it is very cost inefficient since it involves disassembling modules, mobilizing plant, materials and specialized workforce on-site and delaying the commissioning phase and subsequently the building's handover.

For this reason, it is very common that prefab buildings made of 3D modules are pre-assembled at the factory to be subjected to acoustic and thermal tests and then disassembled again for transportation to the final site. The results of these off-site tests can only give us a rough idea of the future compliance of the building, since at the factory the assembled building has not yet been fully built and commissioned. Besides, the results of the on-site tests depend as well on some variables which are difficult to consider at factory stage, such as the site's environment.

The challenge to solve is to develop a series of methodologies and tests which allow evaluating the acoustic and thermal performance of the modules at earlier stages to ensure, or to maximize the possibilities of future compliance.

The target group who could benefit from these methodologies and tests are any prefabricator who wanted to optimize the current process of process of building, assembling, testing, disassembling, transporting and installing on-site. Two main optimizations would be:

1. elimination/minimization of the pre-assembly phase if the results of the off-site tests carried on individual modules were conclusive enough to ensure future compliance of the whole building on-site. This is hard to believe at this stage.
2. Minimization of on-site modifications during commissioning phase if the results of the off-site tests carried on the pre-assembled building were conclusive enough to ensure future compliance of the whole building on-site. This is more realistic, although difficult too.

Contribution of partners

- UNIVPM has led the design and performance of the thermal tests.
- SIEMENS has led the design and performance of the acoustic tests.

Description of the demonstration building

As previously described in D5.4, the modular building (Espacios Vecinales) selected to be used as demonstrator of the use cases was postponed by the client so it will be constructed outside INSITER's timeframe. The demonstrator was a 150 sqm modular building, designed to serve as a space for social activities for the neighbours of the area. The building was designed to have three independent one storey units made of 5-6 modules each. Each unit was to be "connected" to the other two by open air spaces. The building included a multi-purpose main area, restrooms, warehouse, offices, etc. The final location of the building will be Seville. The modules were to be almost entirely produced in the factory of Las Cabezas de San Juan near Seville and then shipped on-site for final assembly.

The selected module is a standard 6000*2700*2500 mm module which corresponds with one of two most common module configurations our factory uses. The materials used are standard and commonly used in our projects, so that the results of the tests are as meaningful as possible.

The drawing of the module and its installation are reported in the figures below.

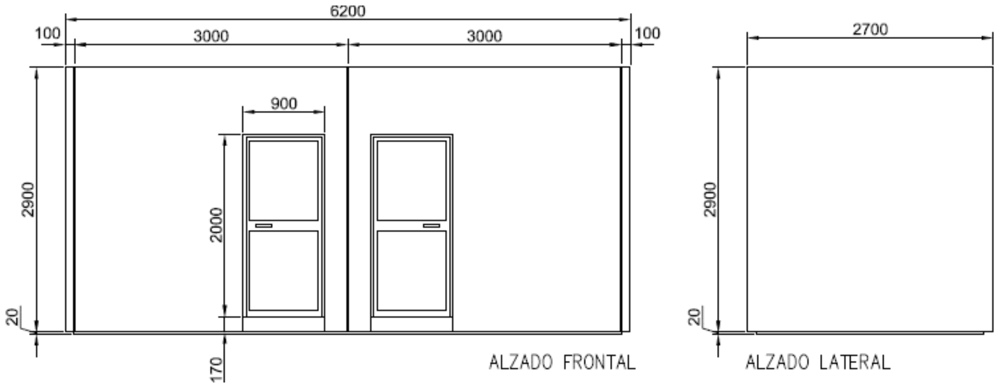


Figure 160: Plant (left) and side (right) views of the module

It consisted on a two room module, whose envelope was made of 6 sandwich panels with the external layers in GRC (Glass Fibre Reinforced Concrete) and an insulation layer in EPS (Expanded Polystyrene). The separation element between the rooms and the roof slab were sandwich panels of thickness of 50 mm and 40 mm respectively with 2 external layers in pre-painted steel and an insulation layer in polyurethane. The thermal characteristics of the prefab panels, the material of which they are made of and their thicknesses are listed in Figure 161 below.

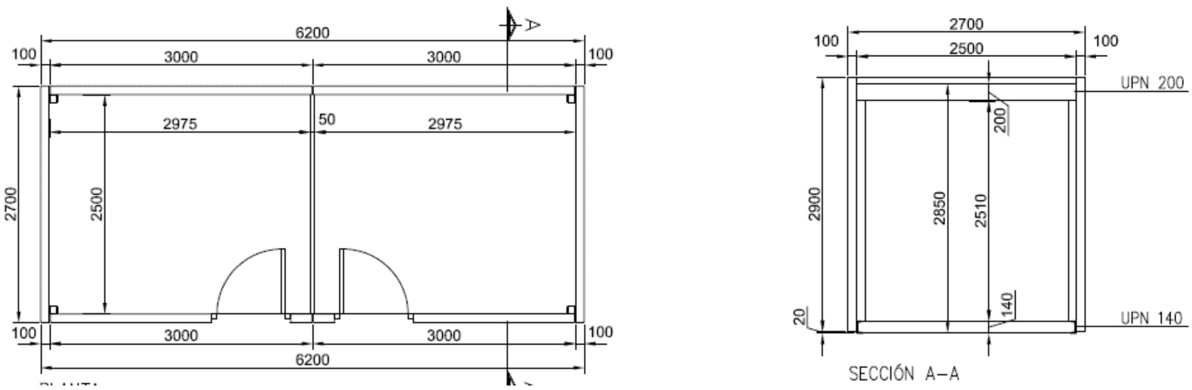


Figure 161: Front (left) and side (right) views of the module

#	Component	Description	Material	Thickness [mm]	Conductivity [W/mK]
1	External Wall	Sandwich panel	GRC	10	0.055
			EPS	80	
			GRC	10	
2	Internal Wall	Sandwich panel	Pre-painted steel	0.5	0.0292
			Polyurethane	49	
			Pre-painted steel	0.5	
3	Door	Single Glass	Glass	3	unknown
			Aluminium frame	40	

Figure 162: Overview of construction materials, thicknesses and conductivity

Figure 163: Photo of two room module

Two doors, with a single glass and aluminium frame, have been mounted on the rooms as visible in Figure 163.

7.3.2 Use case 1: Thermal bridges and airtightness evaluation of the module's envelope to ensure compliance with project requirements

Context: The chosen use case (6.2) corresponds to the measurement of the building thermal performance once installed on-site using INSITER hardware and software. Evaluation of thermal transmittance of the façade, identification of thermal bridges and insulation deficiencies will be carried out. Besides, airtightness will be checked.

Validation objective: The aim is to check if the building complies with project requirements. Some of the tests might be requested by the client following a more standardized approach (UNI-EN 13829 or similar) even though in INSITER such kind of tests will not be performed. Threshold values will be defined according to the specifications and requirements of each project, and always in compliance with current regulations and technical codes.

The following KPIs can be verified in the use case:

- KPI level: energy efficiency
  - KPI: Heat transfer
  - Measurement aspect: Thermal transmittance
  - Parameter: U value

- KPI level: energy efficiency
  - KPI: Heat transfer
  - Measurement aspect: Thermal bridge → The thermal measurements allows to localize the thermal bridges and to estimate their influence (weighting factor) on the global U value
  - The parameter to estimate the thermal bridge influence on the overall envelope is the **ETTV (Envelope Thermal Transfer Value)** that represents a control parameter for building energy use and gives a quantitative value of the energy performance
- KPI level: energy efficiency
  - KPI: Air tightness → unfortunately, with the ultrasound measurement we performed in the demo case, we cannot extrapolate a quantitative parameter as the standard (UNI-EN 13829) requires but we can perform air leakage and infiltration localization.

Use Case	Thermal performance assessment of prefab building				
Relevant Demonstrator	3D prefab module				
Responsible Insiter Parter	DRAGADOS				
Step	**Description**	**Partner**	**Additional information needed**	**Tools to use**	**Comments**
Step 1	Create BIM Model	HVC	Drawings + components/ materials information	IFC viewer	
Step 2	Upload BIM + any other information to server	HVC	n.a	n.a.	
Step 3	Verification of building status prior to tests (general inspection of envelope and inner partitions)	DRA	BIM model + INSITER guidelines + manufacturer's information and manuals	tablet with software INSITER	Follow (or adapt) D1.2 and D1.3 The assembly/installation manual is issued by the Manufacturer, but INSITER self-instruction actions will be presented as annotations and displayed as Augmented Reality.
Step 4	Airtightness and infiltrometer test. ("blower door test")	UNIVPM	Applicable ISO + theoretical values according to Spanish regulation	INSITER thermal testing equipment	
Step 5	Thermography test on envelope (qualitative inspection to detect thermal bridges, insulation deficiencies, etc.)	UNIVPM	Applicable ISO + theoretical values according to Spanish regulation	INSITER thermal testing equipment	
Step 6	Calculation of HVAC systems air flow	UNIVPM	Applicable ISO + theoretical values according to Spanish regulation	INSITER acoustic testing equipment	
Step 8	Upload information (processed data) on server and update BIM model with new layers of information	HVC			
Step 9	Visualization of thermal and airthightness maps	DRA	tests results processed and integrated into BIM model	tablet with software INSITER	INSITER self-inspection additional layers of information (air tightness maps) will be displayed as Augmented Reality including documents with results from the measurements
Step 10	Modifications if need be	DRA	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff		
Step 11	Test repetition	UNIVPM		INSITER thermal and acoustic testing equipment	
Step 12	Upload information on server and update BIM model with new layers of information	HVC			
Step 13	Visualization of thermal and airthightness maps	DRA	tests results processed and integrated into BIM model	tablet with software INSITER	INSITER self-inspection additional layers of information (air tightness maps) will be displayed as Augmented Reality including documents with results from the measurements

Table 53: Storyboard

This use case starts once the building has been fully pre-assembled. The process will begin by the generation of any required BIM content (steps 1 and 2) and a general visual verification of the correct assembly of the building before carrying out any test (step 3). Recommendations from the INSITER guidelines will be followed to carry out the tests. The tests to be carried out can take place in any order (thermal transmittance, thermal bridges identification, infiltration meter test, etc. corresponding to steps 4 to 6).

Thermal maps will be generated and assessed by the quality manager of the project and will be used to support decision making. Besides, it will be shown to workers, so they can visualize the consequences of good/bad manufacture/assembly.

If any of the project requirements - in terms of energy efficiency performance- are not met, the necessary changes will be implemented and tests will be performed again (either using the INSITER tools or following more traditional procedures).

Trials addressing steps 4 to 6, 9 and 13 have been proven with the measurement campaign performed in March 21-24, 2017 by UNIVPM in the DRAGADOS facility in Las Cabezas de San Juan, Seville.

The prefab building module, where the KPIs have been verified, was made with the DRAGADOS CARACOLA modular system described in detail in D5.3.

Figure 163 highlights the two rooms module realized and the QR Codes generated in the *SharePoint* platform. The QR marker is one tool related to IPS integration that allows to tracking prefab-panels and to collect information on the specific building element within the BIM model. Detailed description is reported on D2.4.

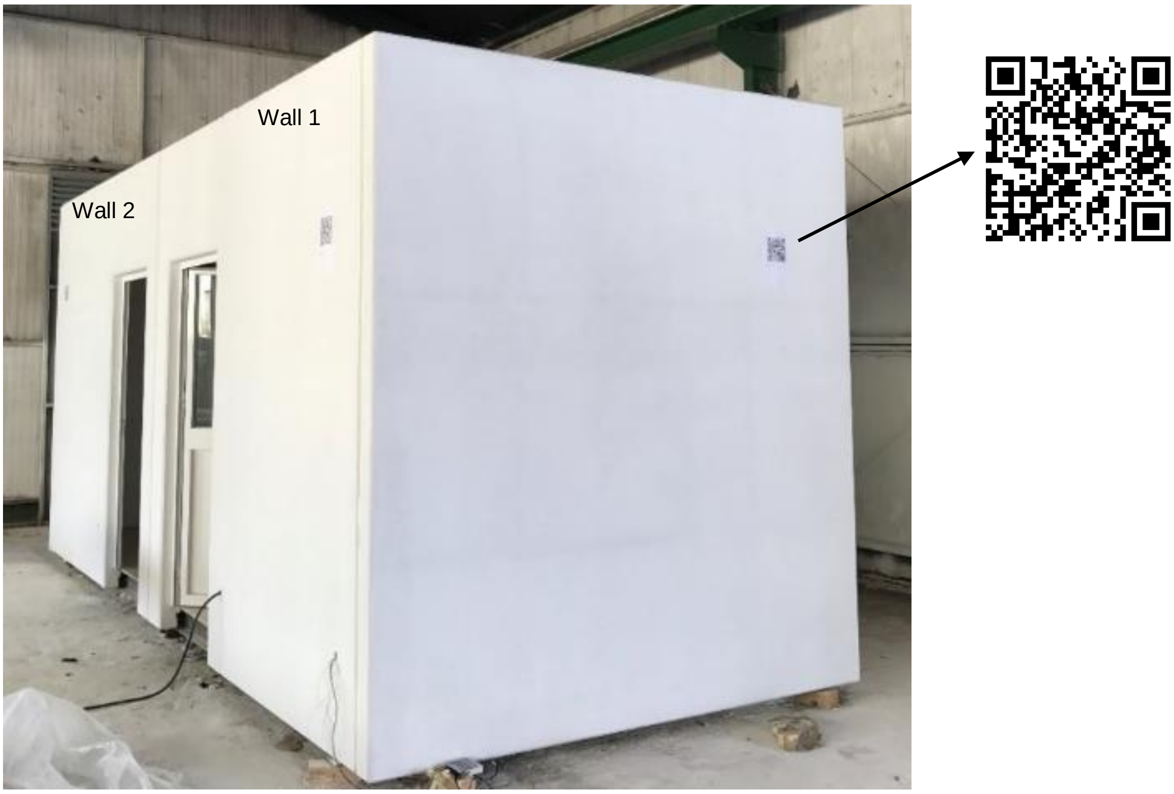


Figure 164: QRs in the module

Thermal bridges and energy efficiency estimation

Thermal measurement setup for thermal transmittance evaluation and preliminary tests

The thermal transmittance of the envelope prefab panels has been estimated by monitoring only one wall of the module. The wall oriented to north-east has been chosen to reduce the possibility that the sensors mounted on the exterior side of the wall have direct solar radiation.

The tested wall was called “Wall 0”. Since the internal partition of the module was made of different material with respect to the envelope panels, also the internal wall (“Wall 6”) has been monitored for thermal transmittance evaluation. To create a sensitive temperature gradient between indoor and outdoor suitable to produce a heat flow through the envelope and the partition wall, a cyclic thermal load has been generated inside the module (room 1) by means of a controlled heater of 9 kW power. To avoid overheating and uniform the thermal field inside the room, a fan was used. The heater and the fan installed in the module are shown in Figure 165.

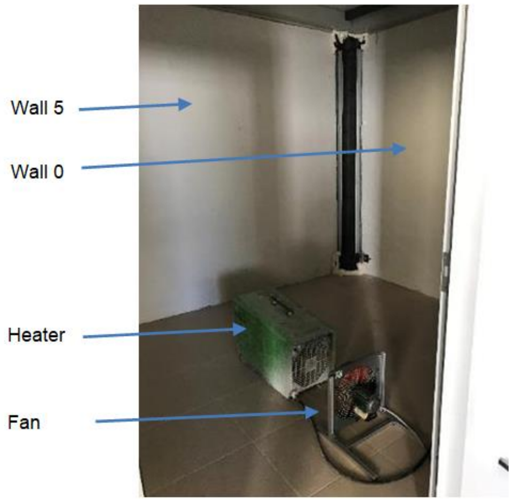


Figure 165: Heating system installed inside the module for thermal load generation

The sensors used to measure the transmittance of Wall 0 are:

- three thermocouples mounted on the internal wall surface ($Twall_{,in1}$, $Twall_{,in2}$, $Twall_{,in3}$) and three thermocouples mounted on the external surface ($Twall_{out1}$, $Twall_{out2}$, $Twall_{out3}$, see Figure 165); the average temperature will represent the surface temperature of the wall indoor and outdoor side,
- one thermocouple located in the proximity of the wall (2 cm away from the surface) to monitor the indoor ($T_{air,in}$) and outdoor air temperature ($T_{air,out}$ as shown in Figure 165),
- a heat flux meter mounted on the external side of the wall. This allows using the UNI 9869 to estimate the thermal transmittance, which will be used to validate the same parameter derived by the INSITER method based on thermal camera measurements (as described in deliverable D2.3),
- a thermal camera (Infratec VarioCam HD) mounted in front of the external surface of the wall (3.3 m away from the panel surface). At this distance, the thermal camera Field of View (FOV) allows framing the entire wall surface with a spatial resolution lower than 1 cm.

The same sensors set-up has been created for Wall 6 where a second thermal camera (Flir S40) has been used. The environmental conditions have been monitored by using an omnidirectional anemometer for the air velocity, a thermal resistance for the air temperature and hygrometer for the humidity. Table 54 reports the list of sensors and the associated uncertainty. The optical specifications of both the thermal cameras are summarized in Table 55 and 56.

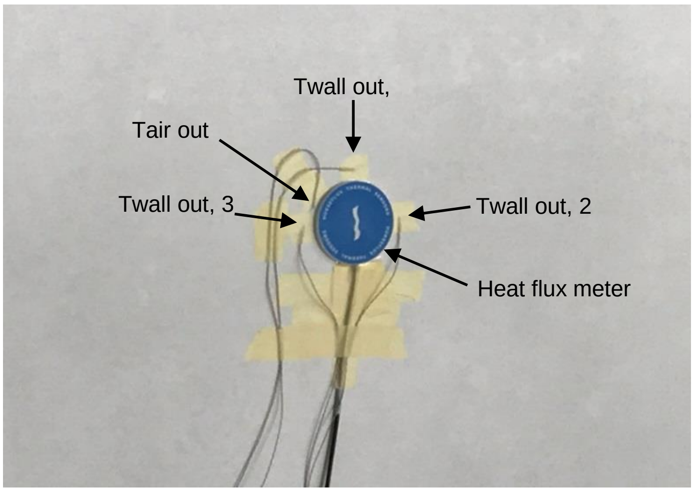


Figure 166: Thermocouples and heat flux meter mounted on the external wall surface (Wall 0)

Sensor	Model	Uncertainty
Thermocouples	Type T	± 0.5°C
Thermal Camera	Infratec VarioCam HD	± 1.5°C
Thermal Camera	Flir S40	± 1.5°C
Heat Flux Transducer	Hukseflux HFP-01	± 3%
Anemometer	Delta Ohm AP3203	± 0.1ms^{-1}
Thermometer PT100	Delta Ohm HP3217R	± 0.01°C
Hygrometer	Delta Ohm HP3217R	± 0.1%

Tabel 54: List of sensors used for the thermal tests

Characteristics Variocam HD		Wall length [mm]	2700
Focal Length (f) [mm]	15	Wall height [mm]	2890
IFOV [mrad]	1.7	***Obtained Values***	
Pixel dimension (Δp) [μm]	17	**Distance [mm]**	**3300**
Horizontal number of pixel (p_h)	1024	**FOV [mm]**	**3828x2882**
Vertical number of pixel (p_v)	768	**Res_{min} [mm]**	**3.74**

Tabel 55: Infratec VarioCam HD specifications

Characteristics Flir S40		Wall length [mm]	2680
Focal Length (f) [mm]	10	Wall height [mm]	2700
IFOV [mrad]	2.6	***Obtained Values***	
Pixel dimension (Δp) [µm]	26	**Distance [mm]**	**2520**
Horizontal number of pixel (p_h)	320	**FOV [mm]**	**1987x2524**
Vertical number of pixel (p_v)	240	**Res_{min} [mm]**	**6.5**

Tabel 56: Flir S40 specifications

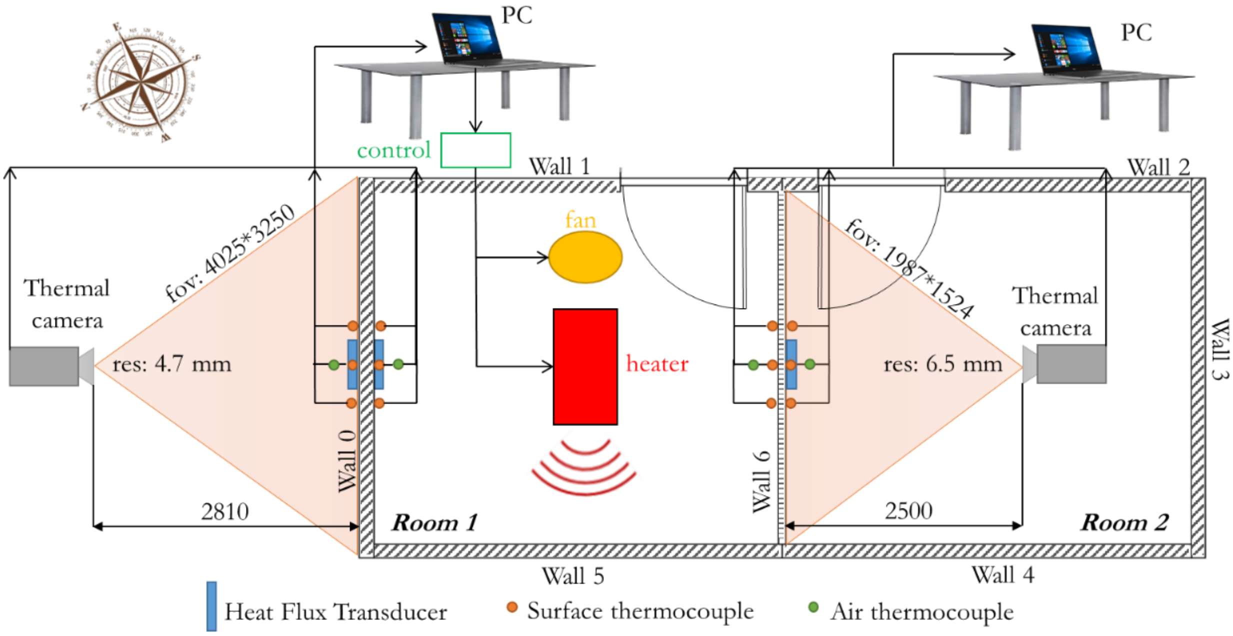


Figure 167: Measurement setup

Figure 167 sketches the complete measurement setup for both the walls monitored (Wall 0 and 6). Figure 168 and 169 show the sensor installation on Wall 0 and 6, respectively.

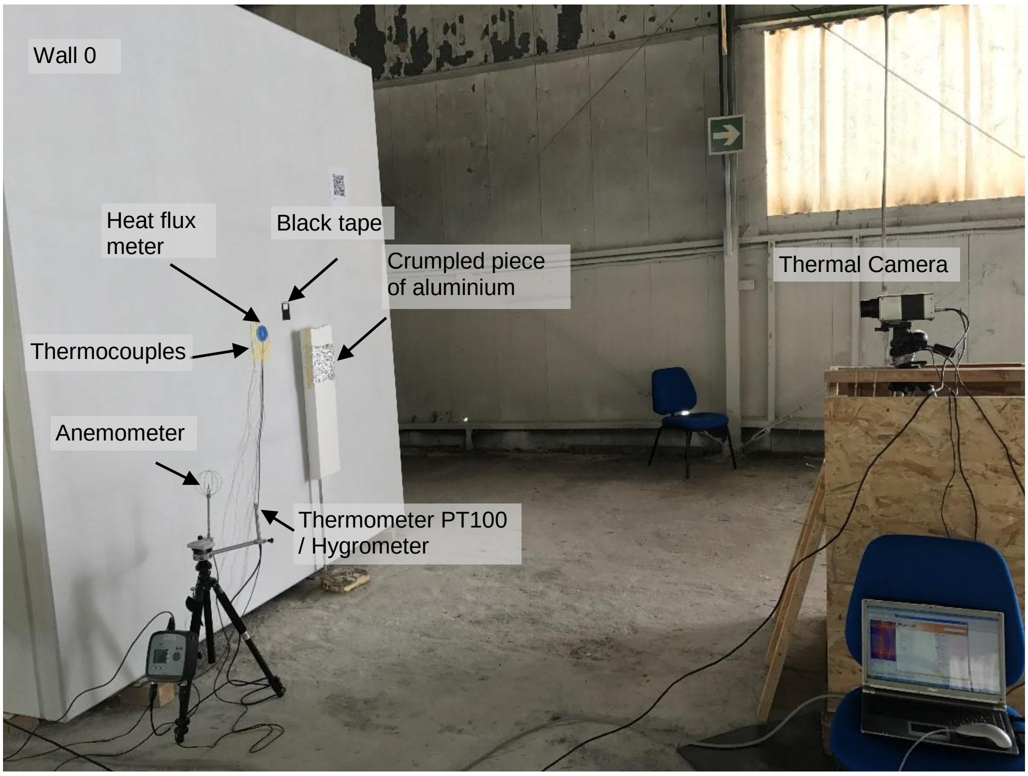


Figure 168: Measurement setup - Wall 0

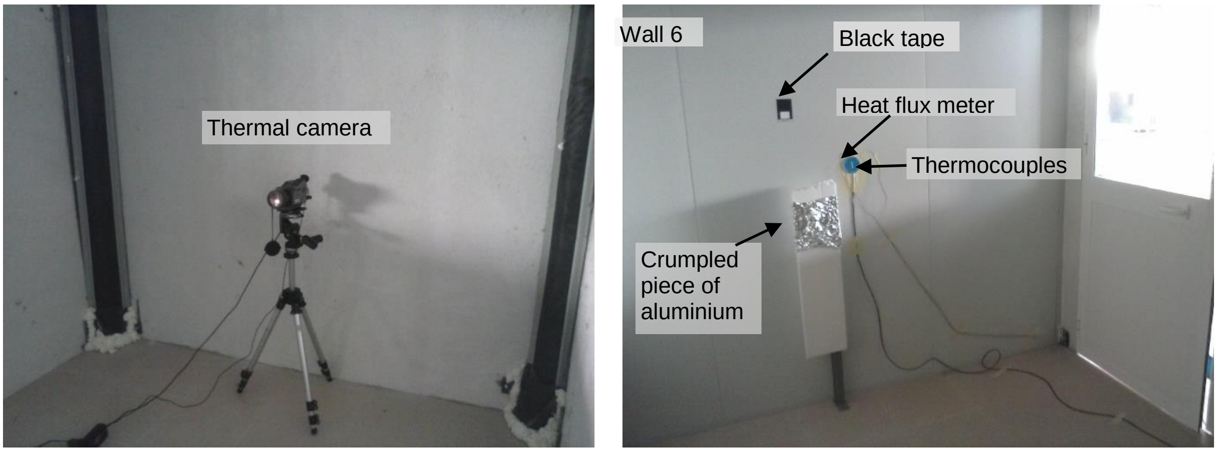


Figure 169: Measurement setup - Wall 6

A preliminary test has been carried out for setting the correct measurement parameters in the thermal cameras software used for the calculation of the surface temperature from the wall intensity of radiation. First, the wall emissivity must be estimated. A good method of ensuring correct emissivity estimation is to use a piece of tape with a known emissivity (0.95), also called 'calibration tape'. This black tape has been affixed to the wall's surface (Figure 167) and left there for a few minutes, in order to assume the wall's surface temperature. Using the known emissivity, the exact temperature of the tape is determined. Because this temperature is the same as that of the surface material, the emissivity settings for the wall material can be derived.

A second parameter to be identified is the reflected temperature, which takes into account for the reflection of the ambient temperature that influences the temperature readings from the thermal imaging camera. To estimate the reflected apparent temperature a crumpled piece of aluminium foil has been used as shown in Figure 170.

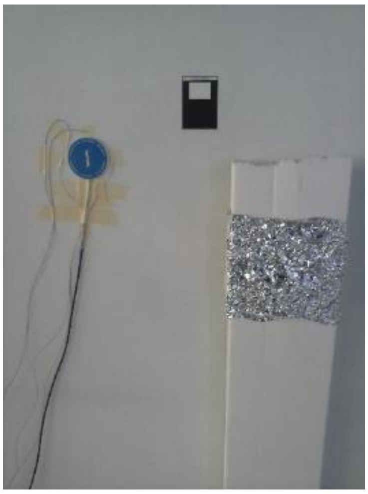


Figure 170: Rumpled piece of aluminium foil and black tape with known emissivity

Contact sensors (e.g., heat flux meters and thermocouples) can estimate accurately the thermal flux and the temperature gradient across the wall only if the hypothesis of mono-dimensionality of the heat flux is valid. In order for this hypothesis to be verified, the sensors must be installed far from inhomogeneities or discontinuities of the thermal field, like, for example, thermal bridges. A second preliminary test has been thus set up to identify the correct position to install the sensors: the wall surface has been framed with the thermal camera during a heating cycle creating a thermal load on the room and an artificial thermal gradient between internal and external wall surface. The thermogram (surface temperature distribution) measured by the thermal camera revealed the position of thermal discontinuities as metallic internal frame and connections between wall and ceiling and floor (red areas in Figure 171). Those areas have different thermal transmittance from the GFR portion of the wall and sensors cannot be mounted in their vicinity. The correct position has been indicated in Figure 171.

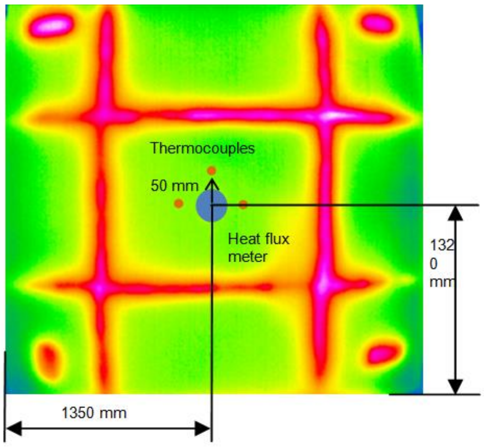


Figure 171: Heat flux meter and thermocouples positioning

Thermal tests

Several tests have been performed to identify the best conditions and sensor installation for obtaining the most accurate estimation of the thermal transmittance of the module's walls. In this report only two tests will be reported:

- Test #1: run by imposing a cyclic thermal load inside the module with a duration of 4 hours and 6 repetitions;
- Test #2: run by imposing a cyclic thermal load inside the module with a duration of 4 hours and 7 repetitions.

Test #1

The test has been conducted by imposing a cyclic thermal load consisting in a heater phase of 2 hours with a set point temperature of 35°C and a natural cooling phase of 2 hours in which the surface temperature of the Wall 0 inside the module decreased up to 27.7°C.

The thermal cycles have been set considering the phase shift of the prefabricated panel (about 20 min) and the time to reach the temperature set point (about 1h).

Then, the measurement and estimations obtained via Thermal Camera (ThC) were compared with the ones obtained by means of contact sensors (thermocouples, TC and heat flux meter, HF) in terms of:

- surface temperature profiles
- thermal flow
- and thermal conductance of the wall (C) calculated according to the standard ISO 9869.

The procedure to calculate thermal flux and conductance, with associated equations are described in detail in deliverable D2.3. Table 57 summarizes the conditions of the test.

Test date	**21/03/2017**
Parameter	***Value***
Initial environmental temperature	14.4°C
Initial reflected temperature	13.8°C
Heating phase duration	2 hours
Natural cooling phase duration	2 hours
Number of cycles	6
Total test duration	24 hours
Time start	10:30
Time stop	10:30
Sampling time thermocouples	5 seconds
Sampling time thermal camera	30 seconds

Tabel 57: Test conditions

Figure 172 and Figure 173 show the temperature profiles measured on Wall 0 and Wall 6 respectively.

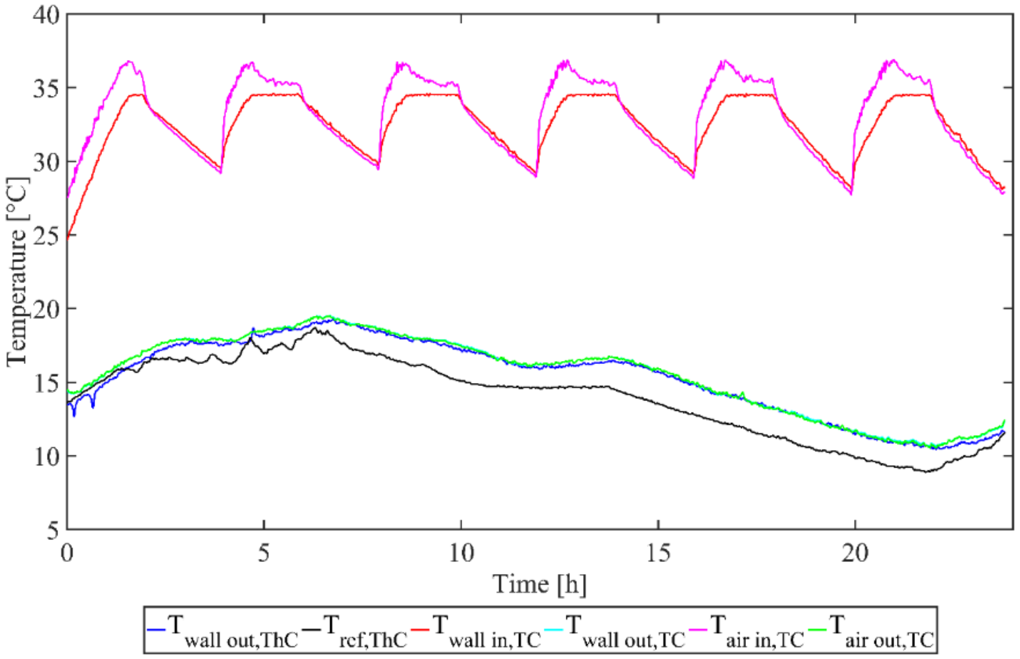


Figure 172: Temperature profile on Wall 0 ($T_{wall\ out,\ TC}$ is superimposed on $T_{air\ out,\ TC}$)

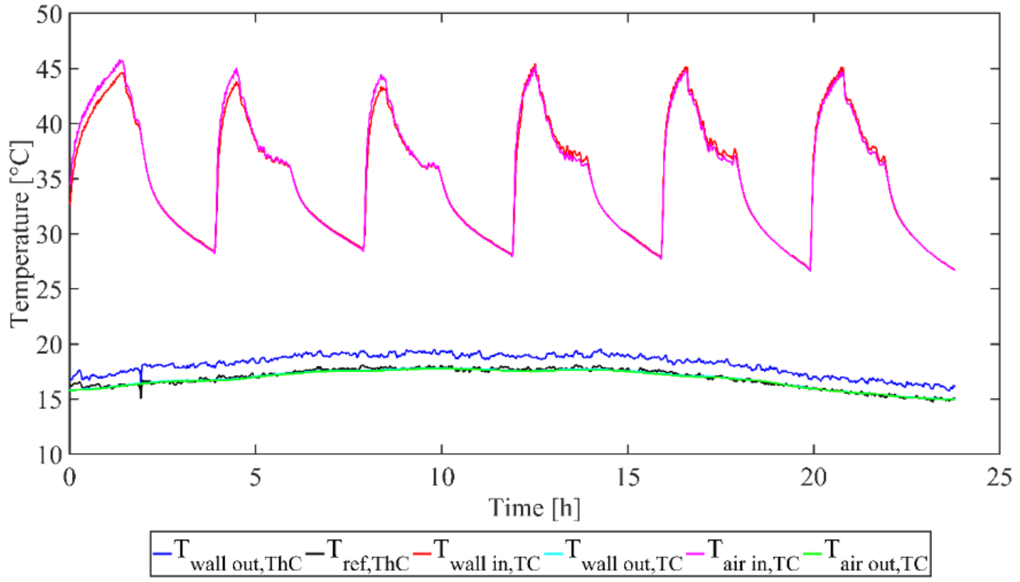


Figure 173: Temperature profile on Wall 6 ($T_{wall\ out,TC}$ is superimposed on $T_{air\ out,TC}$)

Figure 174 and 175 show the heat flow profiles measured by the heat flux meter (black) and calculated from the temperature data (thermogram plus contact thermocouples, blue) on Wall 0 and Wall 6 respectively.

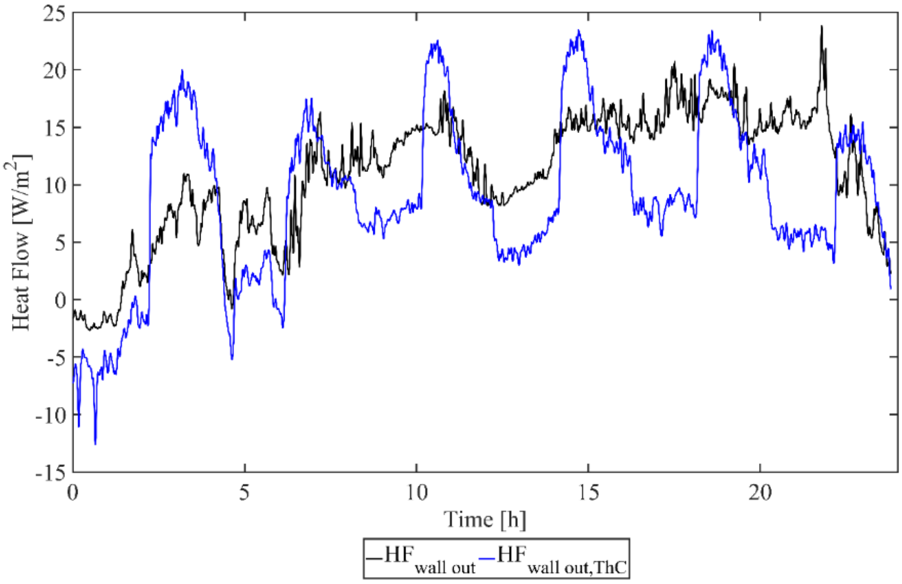


Figure 174: Heat flow profile across Wall 0

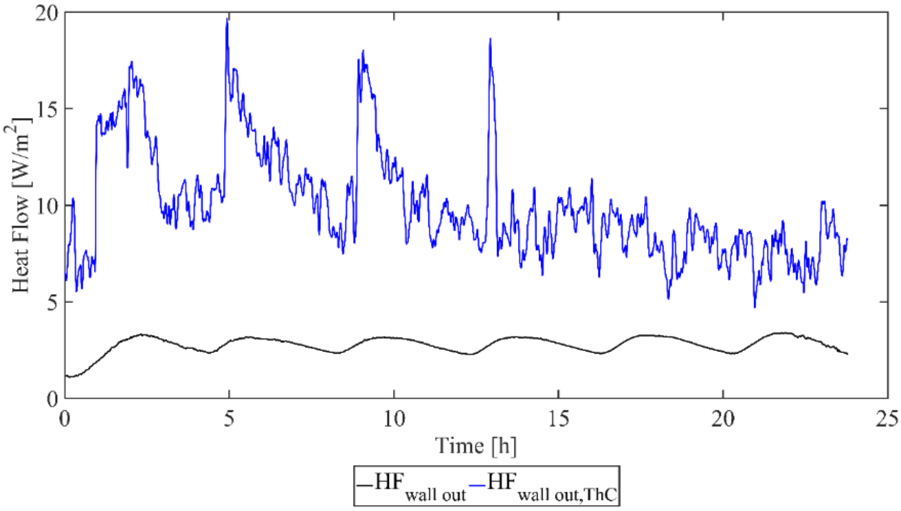


Figure 175: Heat flow profile across Wall 6

Figure 176 evidences that the thermal flow measured by the heat flux meter on Wall 0 is contaminated by noise and the flow induced by the thermal cycle is not recognizable. This is due to the fact that the heat flux meter is mounted on the external surface of the wall where the environmental conditions (temperature and air speed changes continuously due to the daily cycle and wind presence). Therefore, the measured thermal flow is completely buried into the environmental thermal noise. On the contrary on Wall 6 (Figure 177) the heat flux meter is inside the closed room, where the environmental conditions are kept constant and therefore the SNR is high and flow measured very stable (black profile in Figure 177). In the case of Wall 6 the flow is estimated from the thermal camera data, which suffers the most because the wall is a sandwich panel with pre-painted steel and polyurethane that has very low conductivity (0.0292 W/mK) and low surface emissivity. The radiative part of the thermal wave affecting the wall is very limited.

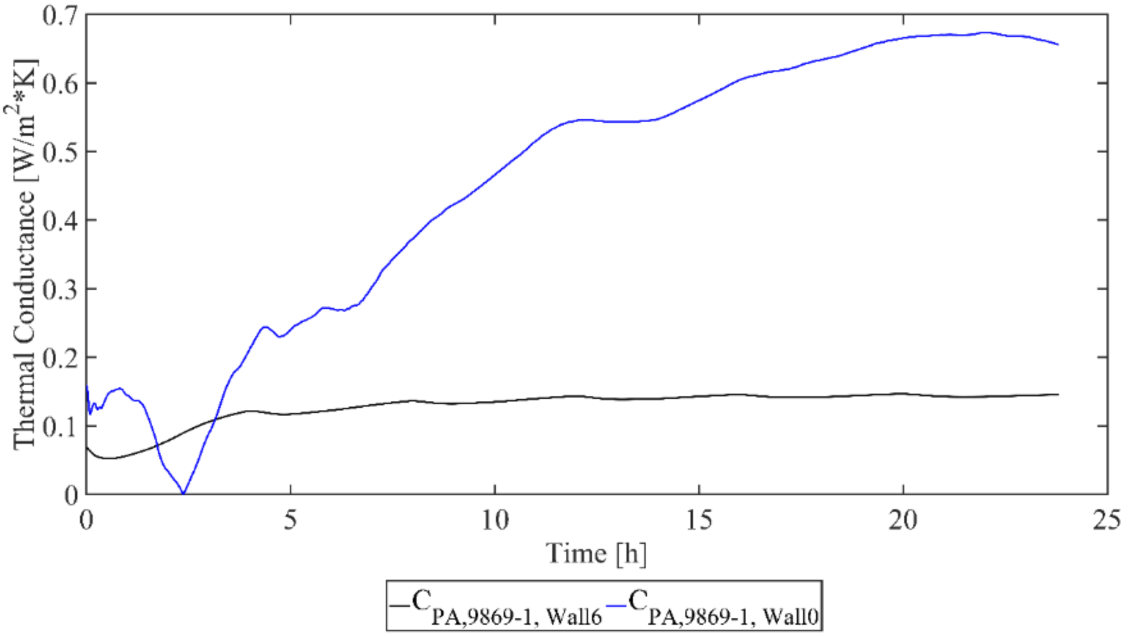


Figure 176: Thermal conductance evaluated in accordance with the standard ISO 9869-1 for Wall 0 (blue curve) and Wall 6 (black curve)

The data registered with the contact sensors (TC and HF) have been processed in accordance with the standard ISO 9869-1 for the in-situ thermal transmittance assessment. In Figure 177 the thermal conductance calculated with the progressive average method, according to the standard, is shown for both the walls observed.

The walls conductivity has been then calculated with the INSITER Soft-Sensing methodology based on thermal camera data and its values for Wall 0 and Wall 6 are reported in Tab 58, together with the expected conductivity and the one calculated according to the standard. The expected conductivity can be derived from the panels' conductance included in the producer specification via the following equation:

$$k = C * D$$

where:

- k = conductivity [$Wm^{-1}K^{-1}$]
- C = conductance [Wm-2K-1]
- D = wall thickness [m]

Wall	Conductance [$Wm^{-2}K^{-1}$]	Conductivity [$Wm^{-1}K^{-1}$]	Conductivity [$Wm^{-1}K^{-1}$]		Conductivity [$Wm^{-1}K^{-1}$]	
		Expected	*ISO 9869-1*	***Error [%]***	*Soft-Sensing*	***Error [%]***
Wall 0	0.55	0.055	0.066	**20**	0.053	**3.63**
Wall 6	0.15	0.029	0.015	**25**	0.028	**3.4**

Tabel 58: Expected conductivity and calculated one from test #1 data

Critical issues and improvements

The high level of error in the case of conductance estimated using the standard method (20-25%) can be related to different reasons:

- The high heat capacity of the material gives a very low heat flow across the Wall 0 and in Wall 6 even lower;
- The air velocity in the external environment reduces the signal to noise ratio of the heat flow measured on Wall 0.

To improve the accuracy on the estimation of Wall 0 conductance, another heat flow meter has been mounted on the internal surface of Wall 0 to avoid that the environmental noise negatively affects the heat flow measurement and to increase the signal to noise ratio. Moreover, the external air velocity has been monitored to understand better the effect of the wind on the thermal transmittance assessment in accordance with the standard ISO 9869-1.

Test #2

The second test has been conducted by imposing a cyclic thermal load consisting in a heater phase of 2 hours with a temperature of 40°C, 5°C higher than the first test in order to increase the thermal gradient across the wall. The subsequent natural cooling phase lasted 2 hours and after this phase the surface temperature of the wall inside the module decreased up to 31°C. 7 cycles have been repeated.

As already mentioned, to improve the accuracy of the heat flow measurement a second flux meter has been mounted on the internal surface of the wall while the first has been left on its external surface.

Table 59 summarizes the conditions of the test.

Test date	22/03/2017
Parameter	***Value***
Initial environmental temperature	16.8°C
Initial reflected temperature	16.6°C
Heating phase duration	2 hours
Natural cooling phase duration	2 hours
Number of cycles	7
Total test duration	28 hours
Time start	16:00
Time stop	20:00
Sampling time thermocouples	5 seconds
Sampling time thermal camera	30 seconds

Tabel 59: Test conditions

Figure 177 and Figure 178 show the temperature and the flow profiles measured on Wall 0 respectively.

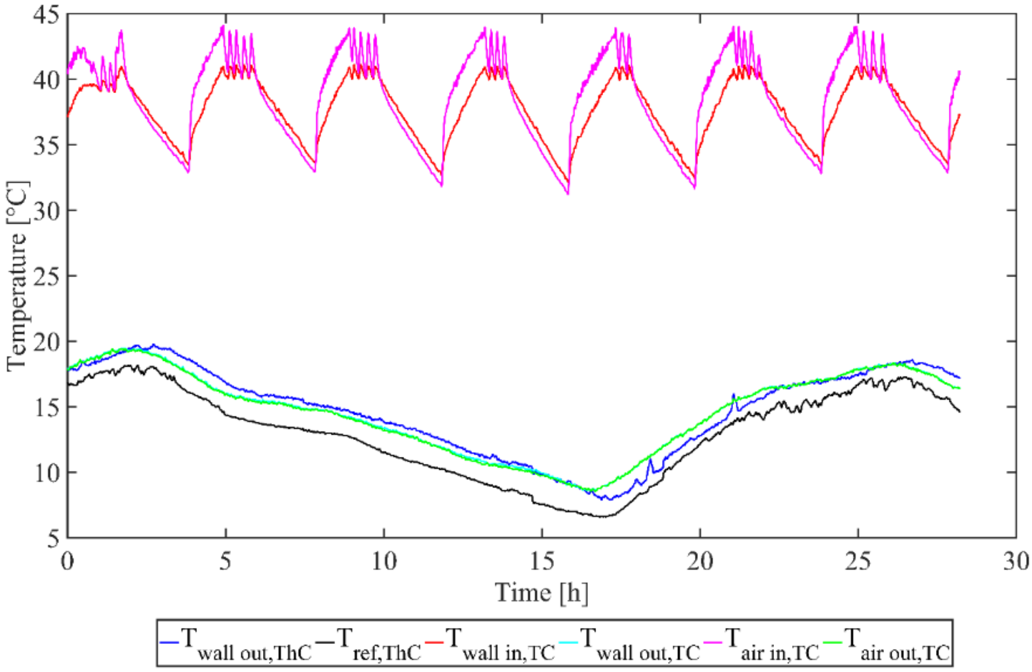


Figure 177: Temperature profile on Wall 0

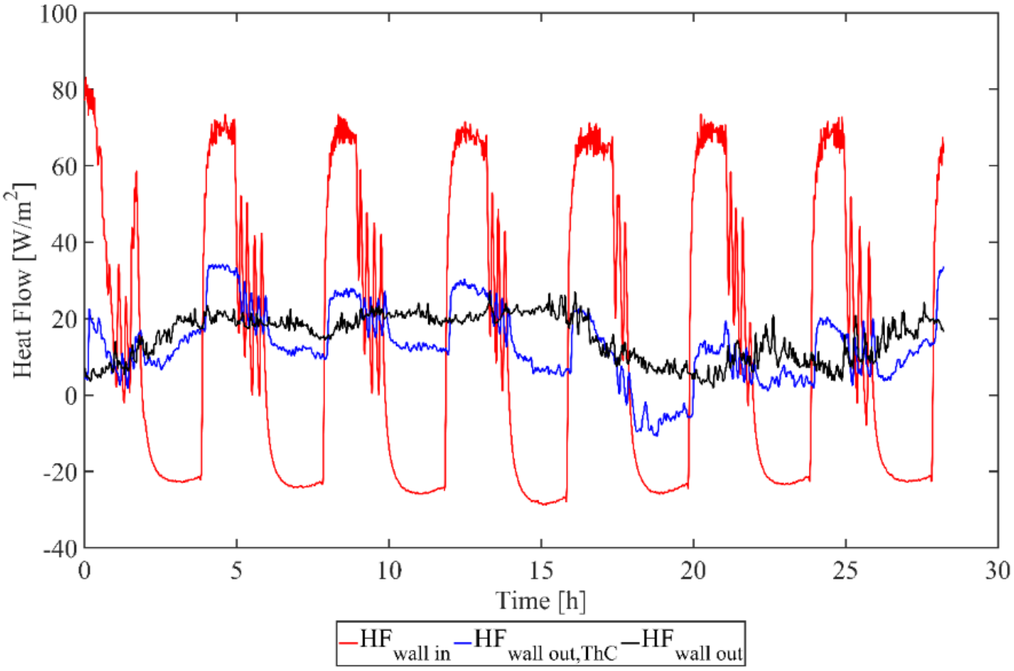


Figure 178: Heat flow profile on Wall 0

Figure 179 reveals that the heat flux meter placed inside measures a greater thermal flow (red profile) than the one placed outside (black profile). It can be expected, as demonstrated in the following calculation, that the accuracy in the conductance estimation will be improved.

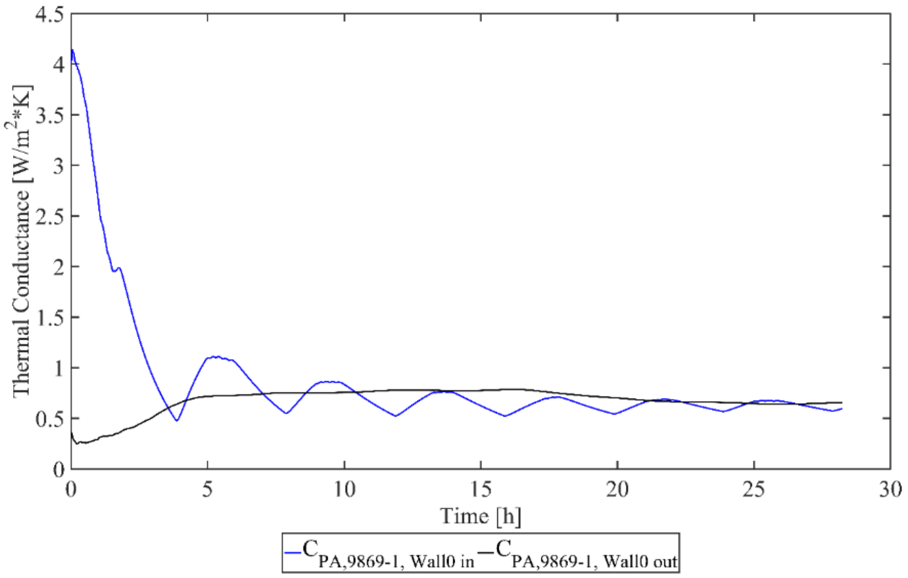


Figure 179: Thermal conductance evaluated in accordance with the standard ISO 9869-1 for Wall 0. Indoor (blue curve) and outdoor (black curve)

The Wall 0 conductance has been first calculated from the measured heat flow in accordance with the standard ISO 9869-1 and its progressive average profile is shown in Fig.179 for both the flows measured by the internal (blue) and external (black) flux meters. The conductivity of the wall has been derived. The wall conductivity has been also evaluated by means of the INSITER Soft-Sensing methodology based on thermal camera data. The expected value of the wall conductivity, the one calculated with the heat flux meter and the one estimated with the INSITER procedure are summarized in Table 60. It can be highlighted that the error in the conductivity estimation is more than halved when using the internal flux meter data. In addition, the accuracy in the estimation of the conductivity with the INSITER methodology increases (the error halved again from 3.6% down to 1.8%). This improvement is due to the increase of the indoor-outdoor thermal gradient from 20°C in the first test to 25°C in the second test.

HF position	***Conductance [$Wm^{-2}K^{-1}$]***	***Conductivity [$Wm^{-1}K^{-1}$]***	***Conductivity [$Wm^{-1}K^{-1}$]***		***Conductivity [$Wm^{-1}K^{-1}$]***	
		Expected	*ISO 9869-1*	***Error [%]***	*Soft-Sensing*	***Error [%]***
Wall 0 HF indoor	0.55	0.055	0.060	**9.1**	0.054	**1.8**
Wall 0 HF outdoor			0.066	**20.0**		

Tabel 60: Expected conductivity and calculated one from test #2 data

Critical issues and improvements

The results show how the environmental conditions affect the measurement accuracy. In fact, the heat flow transducer mounted on the external side of the wall gives a result less accurate (error 20%) than the mounted one on the internal side of the panel (error 9%). The wind velocity fluctuations introduce high frequency variability on the heat flow signal, which affects the conductivity calculation based on flux meter data. Conversely, the INSITER methodology is not affected by the adverse environmental conditions and it allows keeping an error lower than 4%.

Energy saving assessment

The thermal transmittance on the sound area (not affected by thermal bridges) can be calculated based on the conductance value reported in in the previous section and of the air resistance (accounting for the conductive heat transmission on the wall surface) as following:

$$U = \frac{1}{R_{si} + \frac{1}{C} + R_{se}}$$

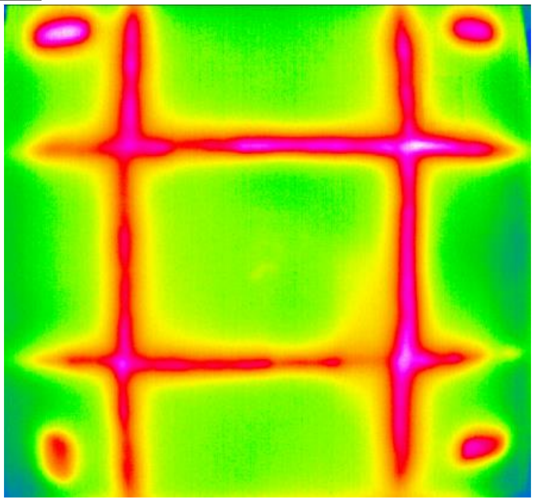
where:

- R_{si}= thermal resistance inner air (0.04 m^2KW^{-1})
- R_{se}= thermal resistance external air (0.13 m^2KW^{-1})
- C = wall conductance (0.54 $Wm^{-2}K^{-1}$)

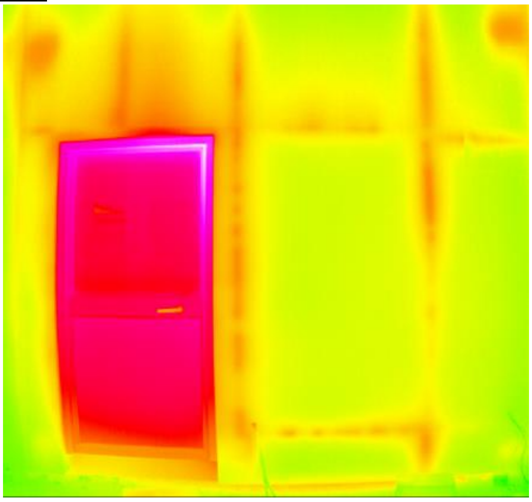
For Wall 0 the thermal transmittance that does not account for thermal bridges is U_{1D}= 0.49 [$Wm^{-2}K^{-1}$]. The subscript 1D states for the fact that the thermal transmittance has been calculated in the sound area where the flow can be assumed mono-directional. This value can be assumed equal for all the module's envelope walls since they are made with the same material and with the same process.

Nevertheless, thermal bridges influence the overall thermal transmittance of the wall and to calculate the real thermal transmittance the weight of the wall area influenced by thermal bridges with respect to the total area of the wall must be evaluated. This weight is called "*Incidence Factor*" (I_{tb}) and it has been described in deliverable D2.3. It can be calculated from the thermograms measured on each envelope wall where thermal bridges are evidenced.

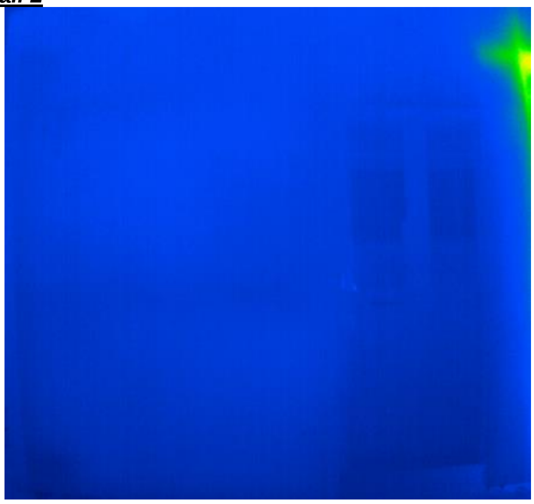
Wall 0



Wall 1



Wall 2



Wall 3

Wall 4

Wall 5

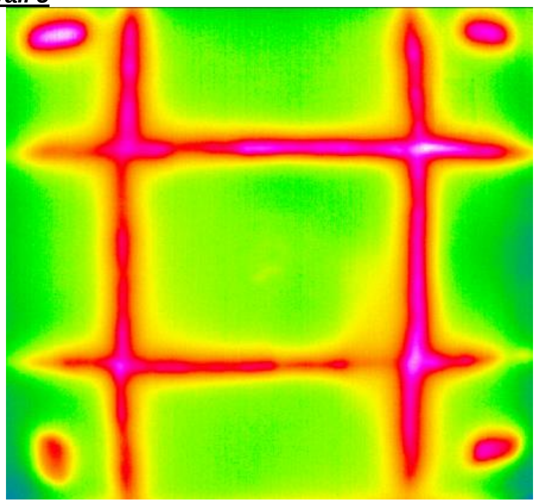


Figure 180: Thermograms of the six envelope walls of the 2-rooms module

The thermograms have been measured with the Infratec VarioCam HD camera framing an exterior wall at a time when a thermal gradient of at least of 10°C was acting between the internal and the external wall surface. Figure 180 shows the thermograms registered on the six external walls of the 2-room module.

From each thermogram, which is a matrix of surface temperatures measured at each pixel of the thermal camera, $T_{pixel,i}$, the incidence factor for the corresponding wall can be calculate as following:

$$I_{tb} = \frac{\sum_{i=1}^{N}\left(T_{in} - T_{pixel,i}\right)}{N * (T_{in} - T_{1D})}$$

where T_{in} is the indoor air temperature, T_{1D} is the temperature of the wall internal surface measured in the sound area (not affected by thermal bridges), N is the number of pixels of the thermogram. The incidence factor has been calculated for all the envelope elements, including the ceiling and is reported in the fourth column of Table 61. The overall U-value of the wall, given in the fifth column of the same table, is thus obtained by multiplying the thermal transmittance evaluated for the sound area by the incidence factor:

$$U_{overall} = U_{1D} I_{tb}$$

Wall	*Area [m^2]*	*U-Value [W m^{-2} K^{-1}]*	*I**	*U-Value (Overall) [W m^{-2} K^{-1}]*
0	7.80	0.492	*1.2957*	0.638
1	8.67	0.492	*1.6646*	0.819
2	8.67	0.492	*1.6646*	0.819
3	7.80	0.492	*1.2957*	0.638
4	8.67	0.492	*1.2957*	0.638
5	8.67	0.492	*1.2957*	0.638
*6**	16.20	0.533	*1*	0.533

I: Incidence factor of the thermal bridges; 6: Roof.

Table 61: Incidence factor and U-value overall for the envelope elements

Once known thermal transmittance of each envelope wall it is possible to evaluate the overall envelope thermal transmittance, the so called ETTV (Envelope Thermal Transfer Value), given by the following equation:

$$ETTV = \frac{12 * (A_{w1} * U_1 + A_{w2} * U_2 + \dots + A_{wn} * U_n)}{A_0} + \frac{3.4 * (A_{f1} * U_{f1} + A_{f2} * U_{f2} + \dots + A_{fn} * U_{fn})}{A_0} + \frac{211 * (A_{f1} * SC_{f1} + A_{f2} * SC_{f2} + \dots + A_{fn} * SC_{fn}) * (CF)}{A_0}$$

where:

- A_{w1}, A_{w2}, A_{wn}: Areas of each opaque wall [m^2], reported in the second column of Table 61
- A_{f1}, A_{f2}, A_{fn}: Areas of fenestration [m^2], it is not accounted for because no windows are installed
- A_0: Gross area of the exterior wall 66.48 m^2
- U_1, U_2, U_n: Thermal transmittance of opaque walls [$W\ m^{-2}\ K^{-1}$], reported in the third and fifth columns of Table 61, for sound and overall thermal transmittance, respectively
- U_{f1}, U_{f2}, U_{fn}: Thermal transmittance of different fenestration types [$W\ m^{-2}\ K^{-1}$]
- SC_{f1}, SC_{f2}, SC_{fn}: shading coefficients of different fenestration types.

The ETTV must be calculated first considering for the opaque walls the thermal transmittance not affected by thermal bridges (U_{1D}) and after the overall thermal transmittance ($U_{overall}$). For this specific case it is:

$$ETTV_{1D} = 6.02\ [Wm^{-2}K^{-1}]$$

$$ETTV_{overall} = 7.91\ [Wm^{-2}K^{-1}]$$

which gives an ETTV deviation (ΔETTV), because of the thermal bridges, of 1.89 $Wm^{-2}K^{-1}$ (31.39 %).

This ETTV deviation allows calculating the energy that could be saved (ΔE) if the thermal bridge would not be present, as following:

$$\Delta E = HDH * \Delta ETTV * 1/\eta$$

where:

- HDH (Heating degree day) represents the demand for energy needed to heat a building, which depends on the specific location of the building and the outside temperature (20.71 kWh/y for Sevilla area)
- η is the heating and distribution efficiency (generally 0.95).

The energy saving is then 41.2 $kWhm^{-2}y^{-1}$ which represents the kWh saved per unit area of the envelope per year.

Thermal bridge localisation

The thermal analysis performed on the 2-rooms module envelope based on the thermograms acquired by the thermal camera can be used also to locate thermal bridges on the envelope itself. Figure 181 illustrates the reconstruction of a 3D view of the surface temperature measured on the envelope elements. The thermograms registered for each wall have been also superimposed to the BIM model of the 2-room module as shown in Figure 182.

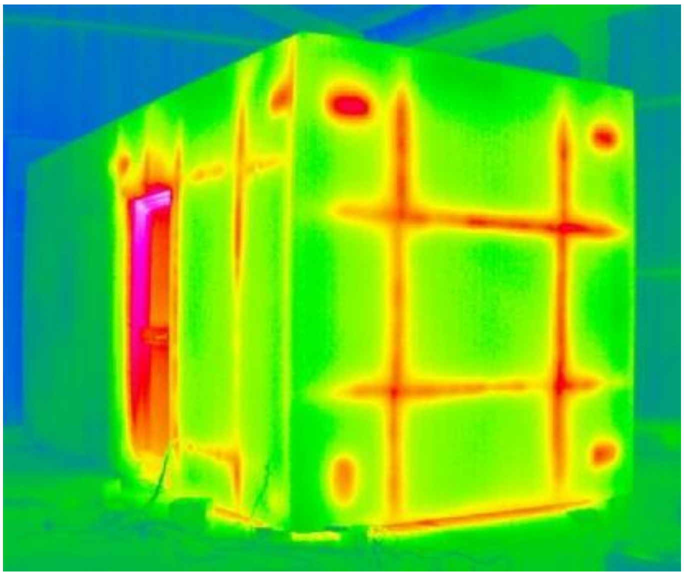


Figure 181: 3D temperature distribution on the envelope surface

Thermal images superimposed on the BIM (front and rear view)

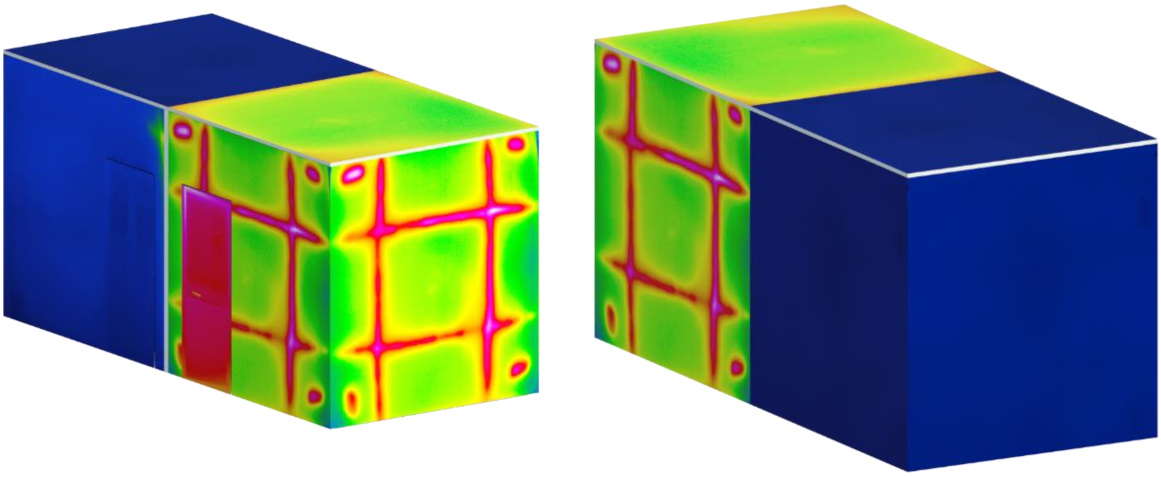


Figure 182: 3D temperature distribution of the envelope superimposed to the BIM model of the 2-rooms module

Air tightness assessment

An air leakage test has been done on the Wall 2 since it presented a door to verify that there were no leaks in the joints. The whole surface has been scanned with an ultrasound probe while an ultrasound generator was placed inside the room.

Measurement setup and procedure

The list of equipment used for the test is given in Table 62 and their arrangement is sketched in Figure 183. A photo caught during the test is shown in Figure 184. As it can be observed from the photo, the operator scanned the entire surface of Wall 2 while the ultrasound generator, located at the centre of the room, emitted ultrasonic waves inside the room.

Tool	Model	Uncertainty
Ultrasound Source	SDT 8	-
Ultrasound Probe	SDT 150	± 1dB

Tabel 62: List of sensors used for the airtightness test

Before starting the measurement, the system must be calibrated, i.e. the ultrasonic detector sensitivity must be set following the procedure described hereafter:

- Switch on the ultrasound generator
- Activate the ultrasonic detector at the lowest level of amplification
- Position the ultrasonic detector outside the room with the door open
- Set the detector signal amplification at the maximum level (before saturation)
- Close the door and start the inspection.

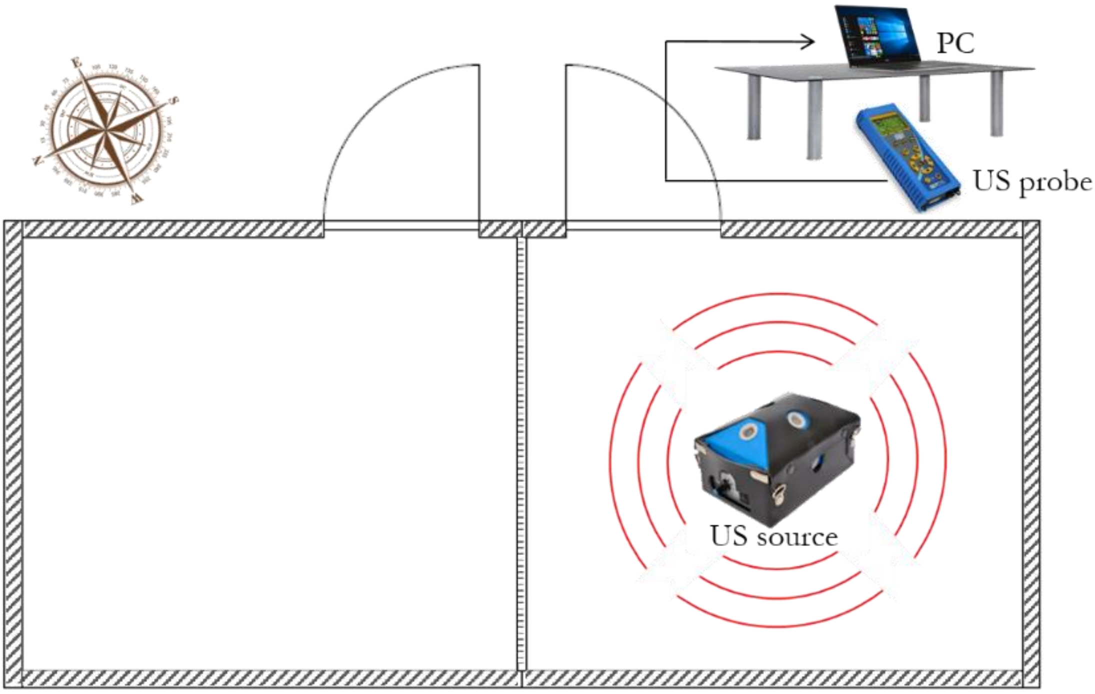


Figure 183: Measurement setup

Figure 184: Ultrasound test

Scan of Wall 2

The test has been conducted by scanning the surface of Wall 2 continuously and recording both the ultrasonic signal and the position of the detector. The ultrasonic signal registered has been plotted in function of the instantaneous position of the probe and a spatial distribution of the ultrasonic waves passing through the wall has been superimposed to the image of the wall itself (Figure 185). The map gives qualitative information about the air leakage entities but allows precisely locating them in the wall. Specifically, it is possible to evidence leaks in the junction on the bottom of the door and in the hole realized for passing the cables.

Figure 185: Ultrasonic signal superimposed to Wall 2 picture

Conclusions for the thermal tests

The thermal test conducted gives many interesting and important indications about the limitation of the actual standard for the thermal transmittance assessment.

The environmental conditions represent the main aspect in the accuracy of the thermal transmittance evaluation. In fact, as shown in the table 26 the wind perturbation and external radiations affect the heat flow meter acquisition and the results are not accurate with an error greater than 20%.

The last test with the heat flow meter mounted inside the mock-up gives a better result with an error greater than 8% that represents the actual uncertainty value found in the literature.

The accuracy increases by using the Soft-Sensing method that gives an error less than 3% in each test done on the Wall 0 and up to 5.5% on the Wall 6. This is related to the fact that the thermal camera allows to measure the conductive component of the flow across the wall and for this reason gives a more accurate result.

Another advantage in the use of thermal camera and Soft-Sensing method is related to the full-field evaluation of the thermal transmittance that allows evaluating the overall thermal transmittance of the component and the global thermal transmittance of the envelope (ETTV). Therefore, the thermal camera allows also to have a quantitative information on the thermal bridges influence on the thermal transmittance of the wall. It means that is possible to evaluate the energy consumption related to the envelope transmittance and the energy saving related to the thermal bridges absence that in this case is 41.2 kWhm-2y-1.

From an industrial point of view, these tests represent a practical way to verify thermal performance of our modules and the materials constituting them in a sensible period (24 hours), quite lower than the time required to test following current standards. They will allow us to detect flaws in our assembly process or in the materials at an early stage, facilitating reparations or replacements. There is no way however to completely ensure the same performance of the final building since that will depend on the correct assembly of the modules on-site.

7.3.3 Use case 2: Acoustic evaluation of the module's façade to ensure compliance with project requirements

Context: This use case corresponds to the measurement of the buildings acoustic performance once installed on-site using INSITER hardware and software. These measurements include evaluation of airborne noise transmittance both for the envelope and the inner spaces, impact noise test, reverberation noise test. Besides, airtightness will be checked using the INSITER hardware

Validation objective: The aim to check if the building complies with project requirements. Some of the tests are mandatory according to the Spanish building regulation (*Código Técnico de la Edification, CTE*) so they will have to be carried out following standard procedures. Threshold values will be defined according to project specifications. A comparison between obtained results can be done. High interaction with SIEMENS will be needed for this last part.

This use case starts as well once the building has been fully assembled. The process will start by the generation of any required BIM content (steps 1 and 2) and a general visual verification of the correct assembly of the building before carrying out any test (step 3). Recommendations from the INSITER guidelines will be followed to carry out the tests. The tests to be carried out can take place in any order (airborne noise, impact noise, reverberation time, etc.) (steps 4 to 7). Acoustic maps will be generated and assessed by the project quality manager and will be used to support decision making. Besides, it will be shown to workers, so they can visualize the consequences of good/bad manufacture/assembly.

Use Case 6.3		Acoustic performance assessment of prefab building			
Relevant Demonstrator		3D prefab module			
Responsible Insiter Parter		DRAGADOS			
Step	**Description**	**Partner**	**Additional information needed**	**Tools to use**	**Comments**
Step 1	Create BIM Model	HVC	Drawings + components/ materials information	IFC viewer	
Step 2	Upload BIM + any other information to server	HVC	n.a	n.a.	
Step 3	verification of building status prior to tests	DRA	BIM model + INSITER guidelines + manufacturer's information and manuals	tablet with software INSITER	
Step 4	Airborne noise test for envelope and inner spaces	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	INSITER acoustic testing equipment	Several points (4) points per building
Step 5	Impact noise test on inner spaces	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	INSITER acoustic testing equipment	Several points (3) points per building
Step 6	Ambient noise test on inner spaces (between modules on the same building)	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	INSITER acoustic testing equipment	Several points (2) points per building
Step 7	Reverberation time test on inner spaces	SIEMENS	Applicable ISO + theoretical values according to Spanish regulation	INSITER acoustic testing equipment	Several points (2) points per building
Step 8	Upload information (processed data) on server and update BIM model with new layers of information	HVC			
Step 9	Visualization of noise maps	DRA	tests results processed and integrated into BIM model	tablet with software INSITER	INSITER self-inspection additional layers of information (acoustic maps) will be displayed as Augmented Reality including documents with results from the measurements
Step 10	Modifications to the building if necessary	DRA			
Step 11	Test repetition	SIEMENS	INSITER guidelines + manufacturer manual + Recommendations from Factoría de Las Cabezas staff	INSITER acoustic testing equipment	
Step 12	Upload information on server and update BIM model with new layers of information	HVC			
Step 13	Visualization of noise maps	DRA	tests results processed and integrated into BIM model	tablet with software INSITER	INSITER self-inspection additional layers of information (acoustic maps) will be displayed as Augmented Reality including documents with results from the measurements

Tabel 63: Storyboard use case 6.3

Acoustics tests

This chapter summarises the acoustic performance indicators for building components, carried in the prefabricated module at the DRAGADOS factory.

Two KPIs are proposed to be determined through the performance of these tests:

1. the sound transmission loss (STL) for partitions or windows,
2. the spatial prominence ratio (SPR) for junctions between components.

Sound Transmission Loss (STL)

By definition, the sound transmission loss (STL) of a homogeneous partition, such as a panel or a window, is given by

$$\mathrm{STL}(f) = 10\log_{10}\left(\frac{\langle|I_{\mathrm{in}}(f)|\rangle}{\langle|I_{\mathrm{out}}(f)|\rangle}\right), \qquad (1)$$

where f is the frequency and $\langle|I_{\mathrm{in}}|\rangle$ and $\langle|I_{\mathrm{out}}|\rangle$ are respectively the average sound intensity measured at the inlet and outlet faces of the partition along its normal axis. Alternatively, the STL may be obtained from the measured sound pressure on the faces of the partition, as

$$\mathrm{STL}(f) = 20\log_{10}\left(\frac{\langle|p_{\mathrm{in}}(f)|\rangle}{\langle|p_{\mathrm{out}}(f)|\rangle}\right). \qquad (2)$$

The STL determines the level of insulation of the partition. In order to determine whether the results of the tests were acceptable, an acceptance criterion needs to be established. The only reference values we have for the acoustic performance of sandwich GRC panel were taken by a certified entity at the factory following the UNE 74040:1984 standard. The airborne noise insulation provided by a panel like the ones in the module envelope is AN= 35,3 dBA.

However, since the acceptance criteria will depend on each specific project, the following approach will be followed. A minimum level curve is set as a requirement, as

$$\mathrm{STL}(f) \geq \mathrm{STL}_{\mathrm{min}}(f). \qquad (3)$$

Alternatively, a minimum level can be specified for a particular frequency range, as

$$\mathrm{STL}(f) \geq \mathrm{STL}_{\mathrm{min}}. \qquad (4)$$

The procedure followed to carry out the tests has already described in other INSITER deliverables. It is however summarised here. The STL is a well-known acoustic quantity and its measurement is described in the international standards. An in-situ method has been proposed for the project, based on the average normal sound intensity over a 1m^2 area on the inlet and outlet faces of the partition. Any standard sound intensity probe may be used. The SoundBrush intensity probe is chosen for the present project, as it allows for geo-referencing of the measured data and (real-time) spatial visualisation. Figure 186 illustrates the measurement principle. The setup relies on a broadband acoustic source, to remain at the same position for the inlet and outlet measurements.

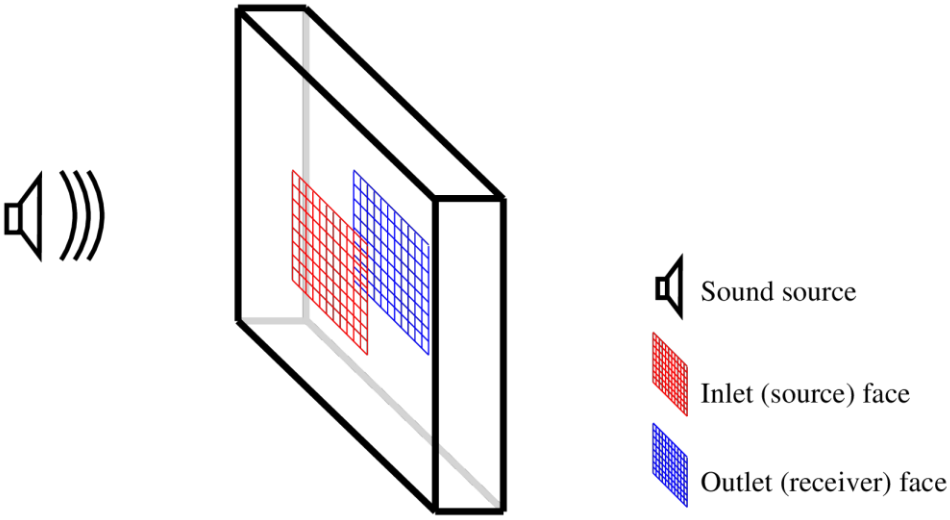


Figure 186: Measurement setup principle for the sound transmission loss (STL)

The following pictures show how the STL measures were taken on the module.

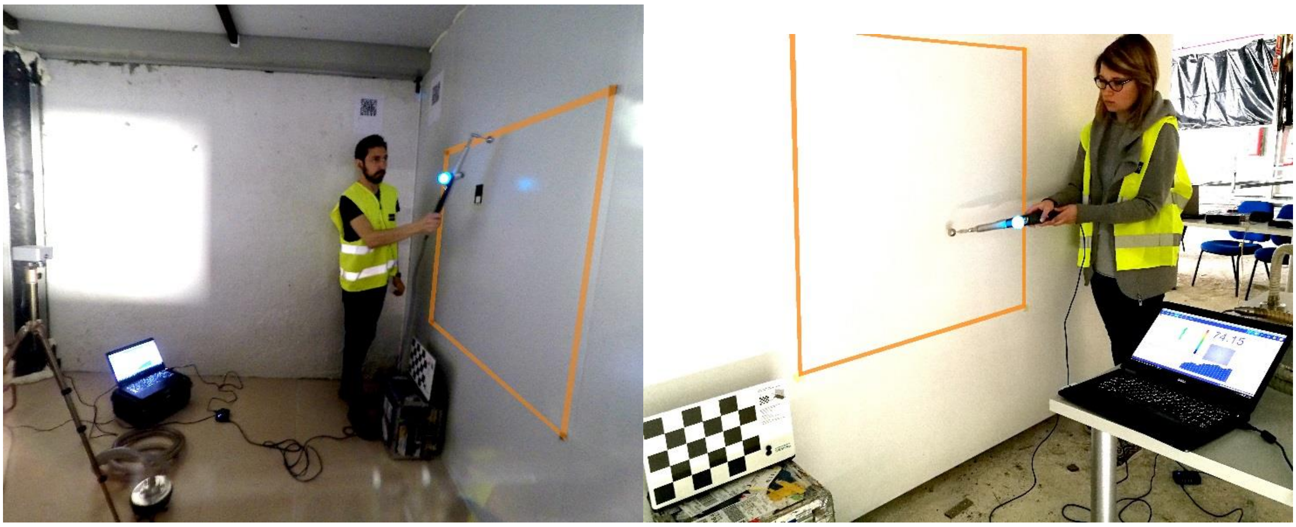


Figure 187: STL measured in the module's inner partition (Wall 6) through sound intensity scans

The sound intensity scans were presented in the form of a graphic 3D sound intensity fields.

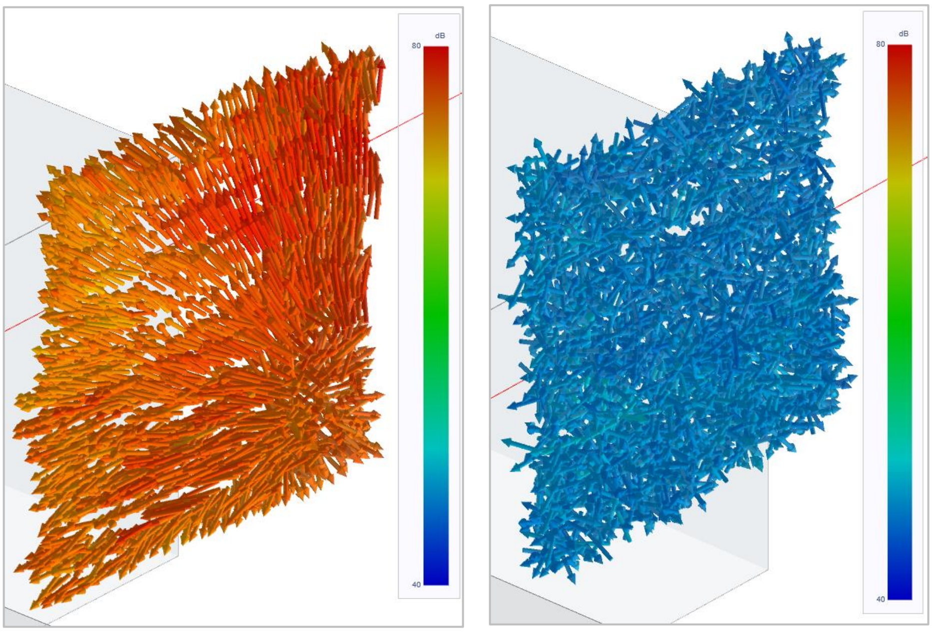
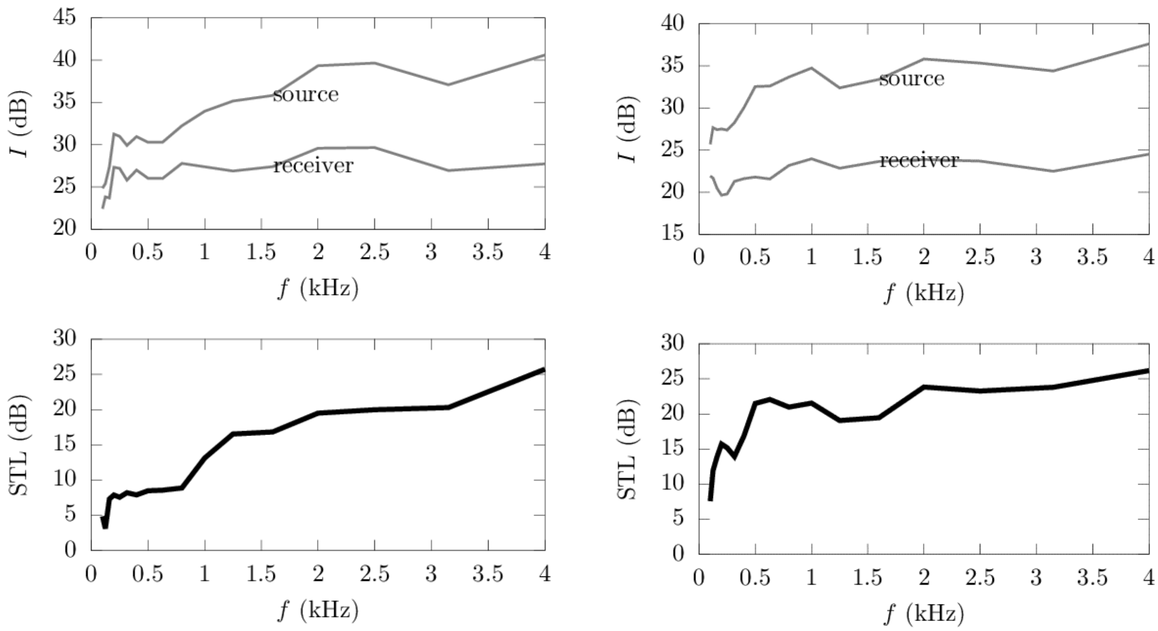


Figure 187: 3D sound intensity field at the inlet and outlet faces of the external panel of DRAGADOS two-room mock-up

Below, Sound transmission loss of DRAGADOS two-room mock-up inner partition and external wall



(a) Inner partition

(b) External wall panel

Figure 188: Sound transmission loss graphics

Spatial prominence ratio (SPR)

The spatial prominence ratio (SPR) is here proposed as the ratio between the maximum and minimum sound intensity level in a region surrounding a junction between two components.

$$\mathrm{SPR}(f) = 10\log_{10}\left(\frac{|I_{\mathrm{max}}(f)|}{|I_{\mathrm{min}}(f)|}\right),$$

Where f is the frequency and Imax and Imin are respectively the average sound intensity measured at the inlet and outlet faces of the partition along its normal axis. As it relates to a sound intensity range, the measurement is inherently relative and therefore does not require the evaluation of the level emitted by the source. Alternatively, the SPR may be obtained from the measured sound pressure on the faces of the partition, as

$$\mathrm{SPR}(f) = 20\log_{10}\left(\frac{|p_{\mathrm{in}}(f)|}{|p_{\mathrm{out}}(f)|}\right).$$

The SPR determines the level of acoustic leakage through a junction. As for the STL, the acceptable threshold will depend on the specific project, so the approach is that each time a maximum acceptable level is set as a requirement, as

$$\mathrm{SPR}(f) \geq \mathrm{SPR}_{\mathrm{min}}(f).$$

Alternatively, a minimum level can be specified for a particular frequency range, as

$$\mathrm{SPR}(f) \geq \mathrm{SPR}_{\mathrm{min}}.$$

The procedure for measuring the SPR is identical to that of the measurement of the sound intensity as described in previous INSITER deliverables. A 3D spatial tracking of the sound intensity probe provides a means of identifying the part of the component or junction responsible for the acoustic leakage. The measurement region must include a reference area that is not susceptible to be influenced by the leakage from the tested junction. Most importantly, tests of nominally identical components must follow the same procedure in order to be comparable.

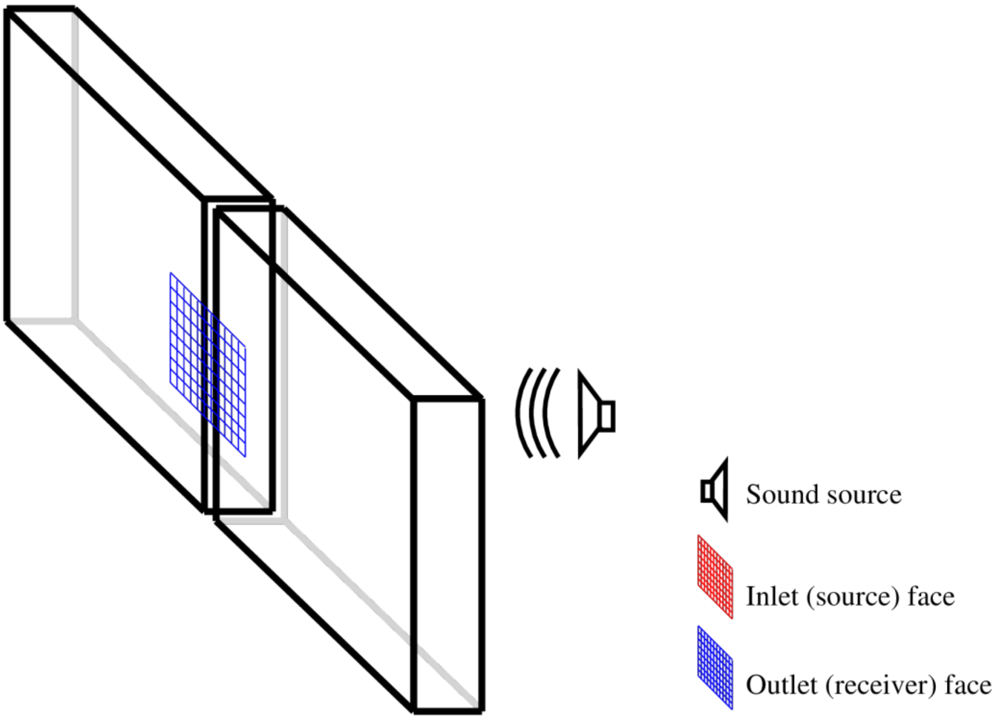


Figure 189: Measurement setup principle for the spatial prominence ratio (SPR)

The SPR was measured in an untreated door junction using a microphone array in a narrow frequency band and using an intensity probe in a broad frequency range. In the pictures below, the results of the measurements are represented graphically.

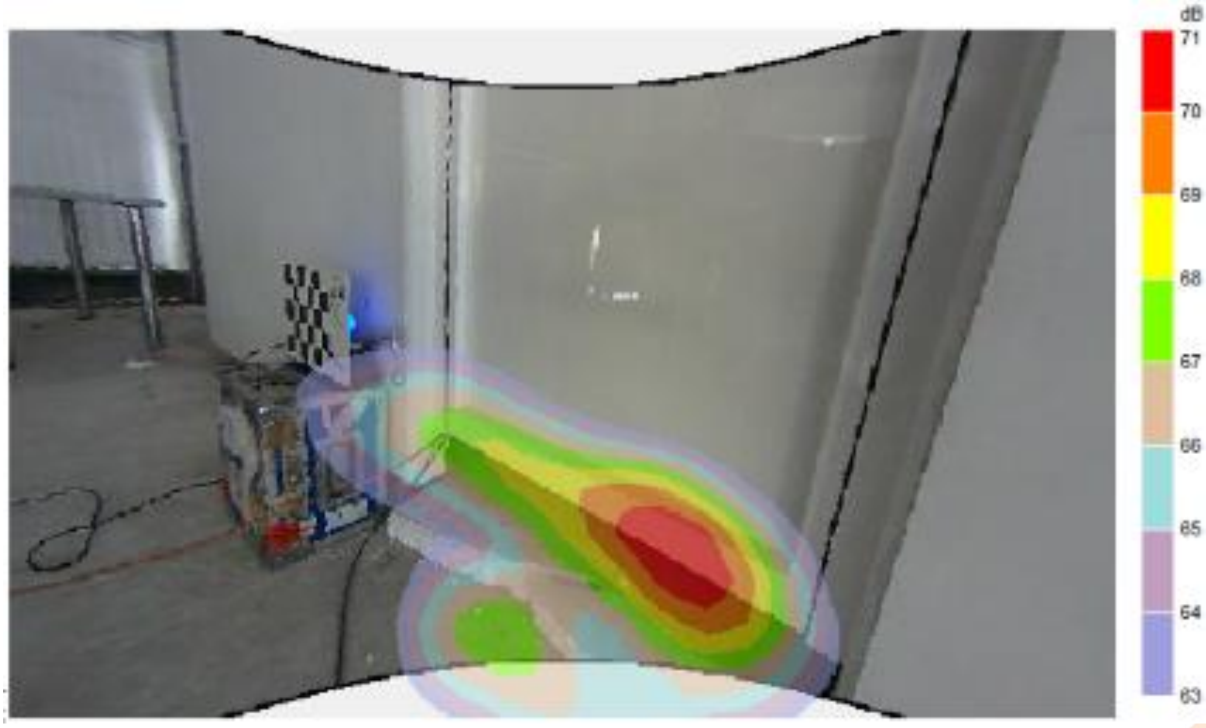


Figure 190: Sound Camera array

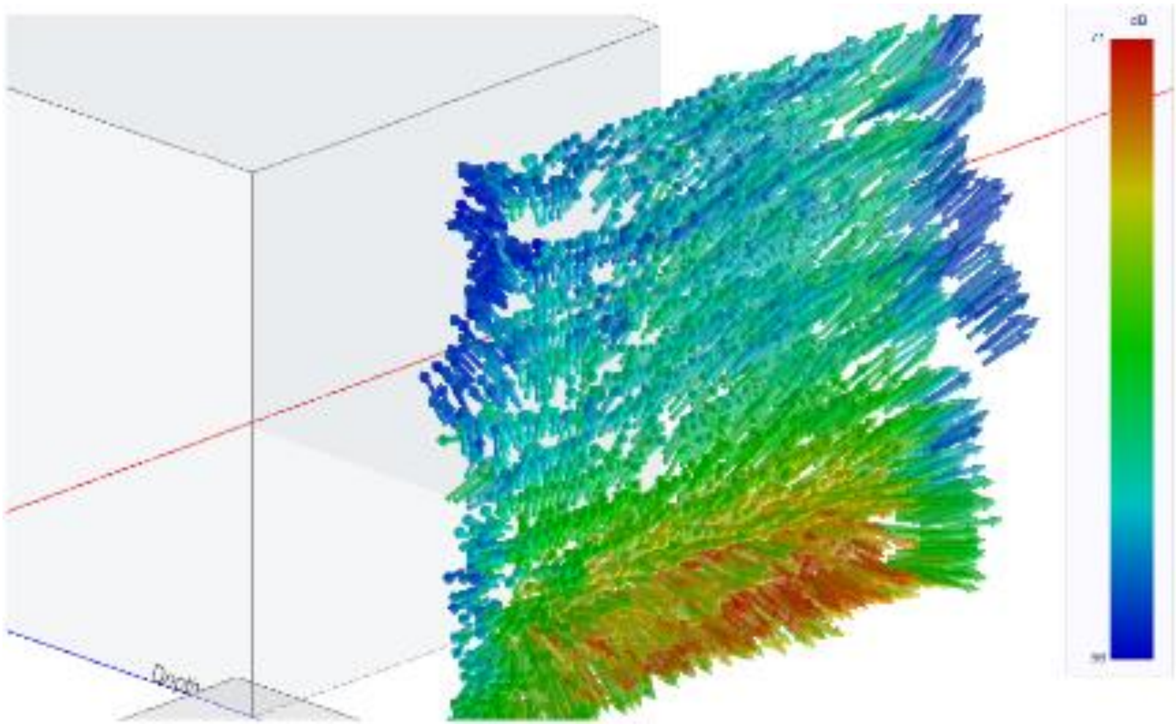


Figure 191: SoundBrush probe

The obtained SPR results measured are in this case:

- $SPR_{2500\text{-}4000\ Hz}$ = 8dB
- $SPR_{100\text{-}4000\ Hz}$ = 15 dB

Conclusions for the acoustic tests

Compliance with KPIs

The tests carried out with the microphone array and the SoundBrush produced high interest in the factory staff since it would allow the quality manager of the factory to detect qualitative and quantitative acoustic problems in the finished products in a few minutes.

Since the regulated tests which are required from clients in order to accept the product handover must be carried out on-site following the applicable standards, the results derived from the use of the INSITER technologies must be compared to the real on-site tests and a relationship must be determined. The aim is to define internal off-site thresholds, more demanding than those required by the client, which can assure the factory QM that the product will comply on-site. Those thresholds would be pre-set for each project, depending on the project requirements and would be compared to the modules acoustic performance while they are being assembled to test the joints and connections among modules.

Compliance with stakeholders

The use of the INSITER acoustic devices, due to the need of silence while they are capturing data, would be restricted to very specific hours, either before or after the working hours. This doesn't seem to be a problem for the Factory staff.

The sensitivity of the devices, the complexity of use, the speed of information post-processing and the way the information is displayed are perfectly in line with the company's needs and expectations.

As per clients, we can say at this stage that although it would be reassuring for them to know the factory is assessing acoustic performance off-site with accuracy, they will only accept on-´site tests regulated by the applicable standards.

7.3.4 Use case 3 – Application and Demonstration of the INSITER BIM based Augmented Reality Apps

Context: For the DRAGADOS factory and module production a further use case has been set-up by DRAGADOS and Fraunhofer IPA in order to demonstrate the application of mobile device (smartphone, tablet or HoloLens) equipped with the INSITER AR applications. Within the DRAGADOS AR use case, special emphasis is on self-instruction support for factory and construction workers. For the factory worker at DRAGADOS the following INSITER AR applications have been applied:

- INSITER HoloLens BIM-based Mixed Reality App, demonstrating the detailed BIM model evaluation and provision of self-instruction data including assembly and construction steps, supporting workers on-site
- INSITER BIM-based Self-Instruction AR App, demonstrating BIM-based process simulations and support for workers for the construction tasks on-site

The demonstration is focused on the visualization of BIM models and new BIM components to be installed or validated onto the real spatial environment. The actors on-site can visualize BIM data of prefabricated building panels and its elements. Thus, all BIM objects and construction components of the prefabricated panels as well as further MEP models of the whole construction module are available in AR. Moreover BIM-based self-instruction data is provided for workers on-site, with a focus on prefabricated modules and window elements for this use case. Workers are able to evaluate on-site work according to design requirements.

Validation objective: The aim is to apply and demonstrate the developed INSITER AR applications and also to verify, if the applications fulfil all the functionalities required by worker on-site as well as to collect feedback from the workers on-site. Factory workers have been asked to provide feedback on the usability of the technologies and this information will be reported in D5.7 Cross-case analysis and benchmarking. The use of the demonstrated applications has been proven to be especially helpful for construction tasks in combination with self-instruction data and BIM elements installations, providing workers with the instructions and information they need.

Within the following section, images of the AR solutions and their on-site demonstration are presented, showing the main aspects of the on-site demonstration as screenshots according to the demonstrated main functionalities of the INSITER AR applications within the DRAGADOS use case:

- Identification and visualization of BIM objects and construction elements, object placement, orientation, on-site visual comparison between virtual BIM model and real on-site situation, construction validation and compliance checking:

Figure 192: INSITER HoloLens BIM-based Mixed Reality App screenshot - BIM element evaluation concerning built-in elements and installed components for the DRAGADOS Use Case Demo in Seville

- Self-instruction and Self-inspection support for on-site construction processes:
  Visual guidance for BIM concerning installation location and assembly task of different window variants. Detailed comparison in Mixed Reality between virtual BIM model and real on-site situation (INSITER HoloLens BIM-based Mixed Reality App, INSITER BIM-based Self-Instruction AR App)

Special emphasis for the DRAGADOS demonstration case is on BIM model evaluation and for self-instruction of detailed 3D BIM elements.

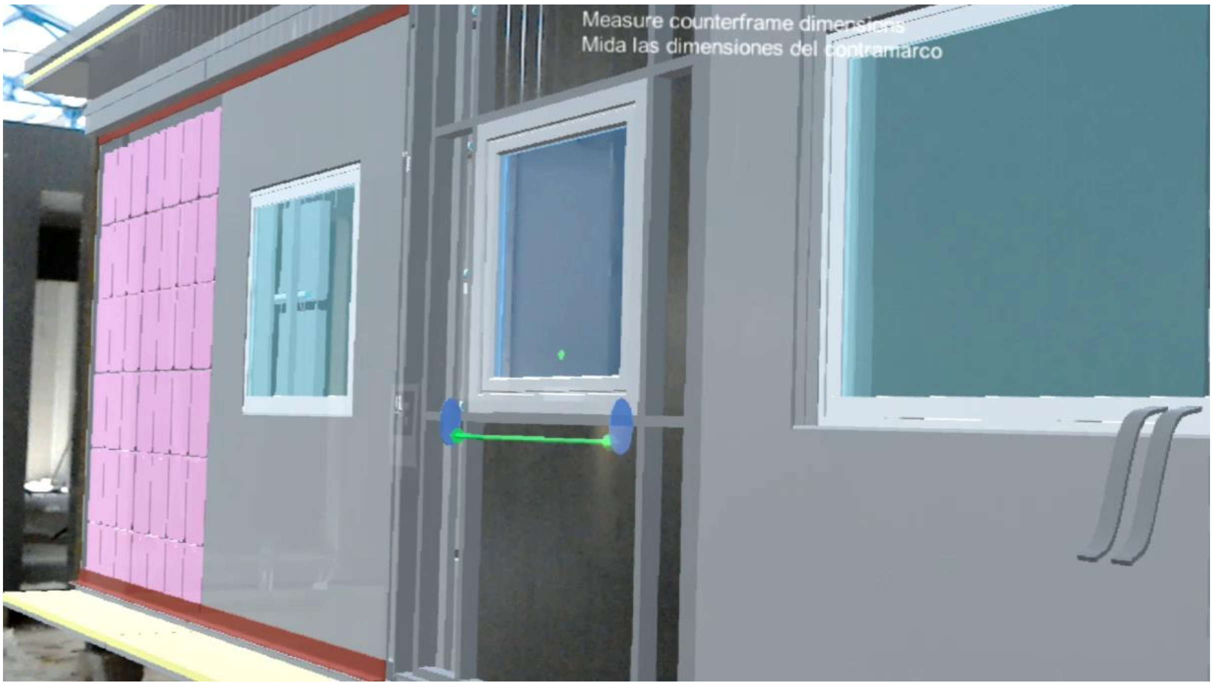


Figure 193: INSITER HoloLens BIM-based Mixed Reality App screenshot – Visualizing self-instruction information for BIM elements and to be installed components for the DRAGADOS Use Case Demo in Seville.

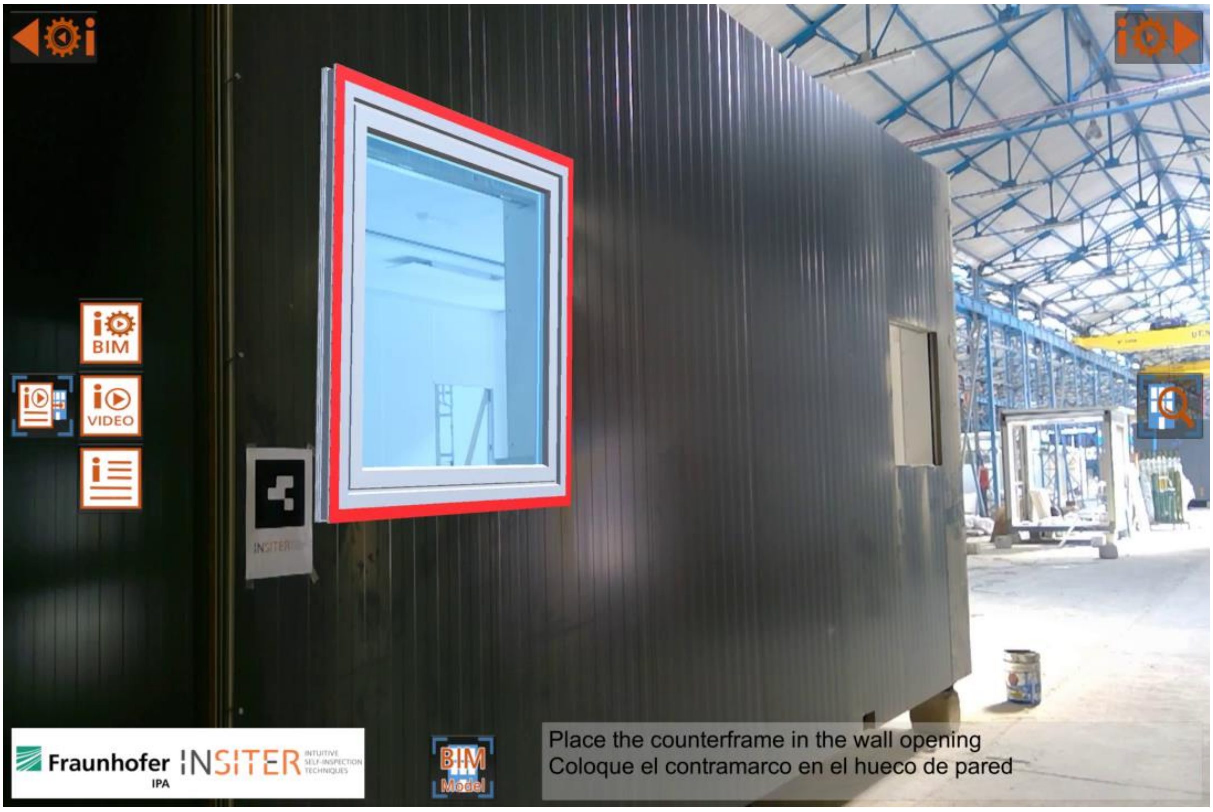


Figure 194: INSITER BIM-based Self-Instruction AR App screenshot - Visualizing self-instruction information for BIM elements and to be installed window components for the DRAGADOS Use Case Demo in Seville on tablet computers

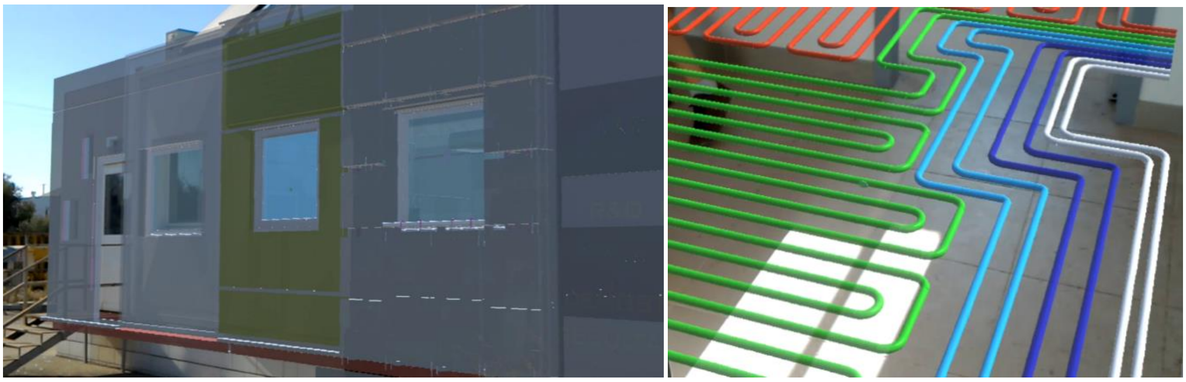


Figure 195: INSITER HoloLens BIM-based Mixed Reality App screenshot - BIM and MEP elements evaluation concerning built-in elements and installed components for the DRAGADOS Use Case Demo for a produced prefabricated module in Seville outside the factory.

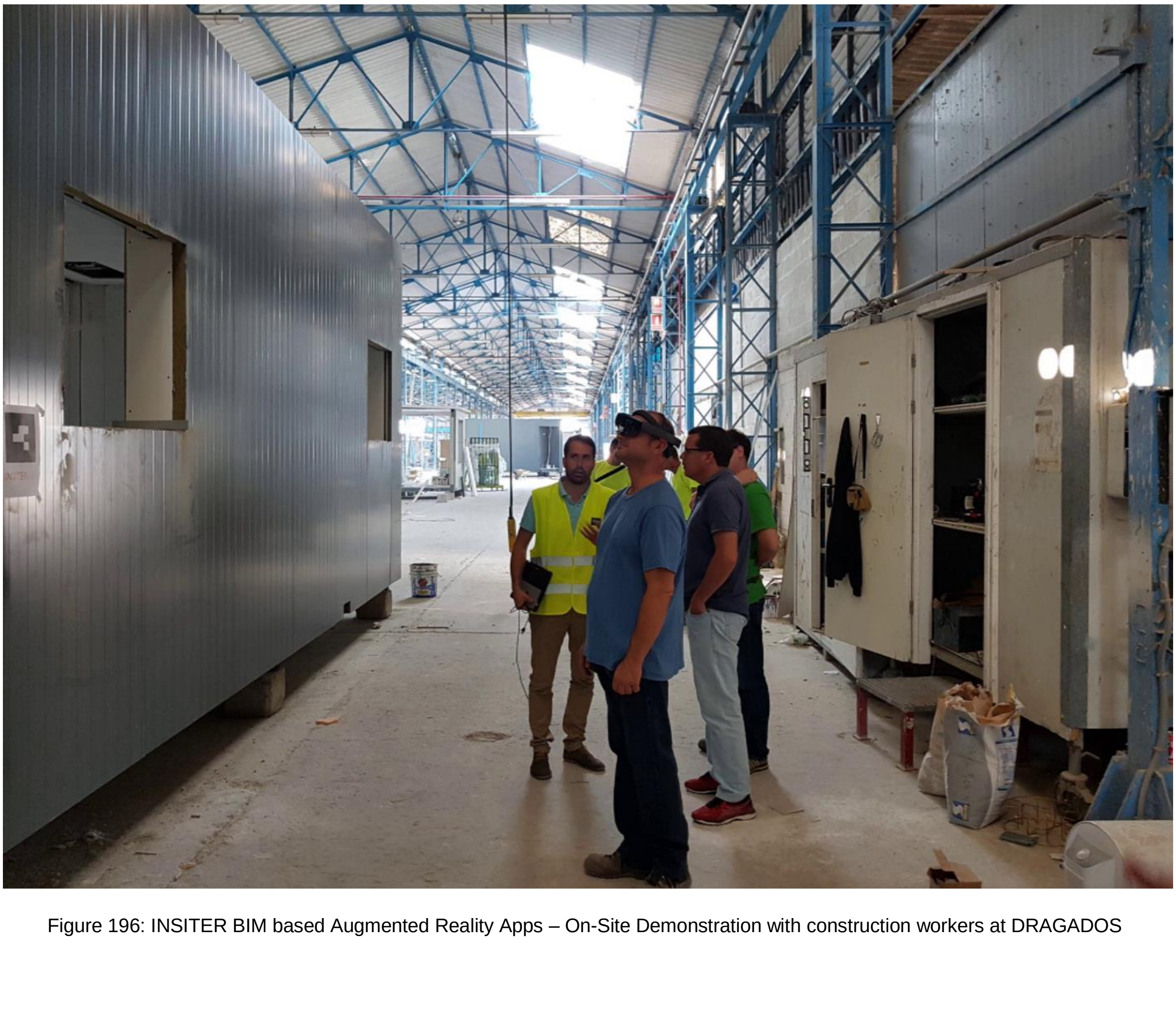


Figure 196: INSITER BIM based Augmented Reality Apps – On-Site Demonstration with construction workers at DRAGADOS

8. Conclusions

The INSITER methodology has been validated successfully against the 6 demonstrators and 16 use cases in D5.4. Due to adjustments and changes in the demonstrators availability 15 use cases have been tested actively on site and at factory level. These results are documented in this deliverable under the sub-headline of D5.5. The use case approach generically was quite helpful to identify the shortage of applicable technologies or bad process flow in different phases of a project realisation in order to assure and enhance the quality of the INSITER tools' applicability on site. Nevertheless the tools and the hardware needed for testing have been explicitly and exhaustively developed, analysed and described in WP2. D5.4 harmonised the inputs of WP1, 2, 3 and 4 to check the feasibility of the application at the factory and on site. The follow up action starting at M37 was to perform the foreseen testing documented in the overview and to check the relevance of the results against the expectations precisely defined by KPIs that are identified in WP1 embedded in the software solution of the dashboard suite developed in WP3. The dashboard suite shows how the collected data are evaluated and rated against given thresholds. The functionality of the suite is documented at a movie available at the SharePoint of the INSITER project. The contents of the analysis contain a building physics analysis dealing with U-value and acoustics -see e.g. chapter 4 Enschede demonstrator- reliability of structure – see e.g. 5 Pisa demonstrator-, preferred materials and their assembly demands – see e.g. chapter 3 Delft and chapter 7 demonstrator Seville- and the influence on indoor climate - see e.g. chapter 6 Valladolid demonstrator. The applied testing and data harvesting technologies are described in WP1 explicitly in D1.4 Calculation and analytical methods for building components, D1.5 Measuring and diagnosis solutions, D1.6 Calculation and analytical methods for MEP/HVAC components and D1.7 Measuring and diagnosis solutions for inspecting MEP/HVAC components. Furthermore in different workshops related to the sites and the performing contractors and especially in the workshops at the Enschede site in May 2018 and at the DRAGADOS factory at Seville at the 25th and 26th September 2018 the set-up and results of demonstration activities has been presented and discussed involving different stakeholders.

Moisture detection and assessment				
KPI (2)	Application level	Measurement aspects	Measurement instruments	Measurement parameters [Units]
Moisture coverage	Envelope area (inside and/or outside) / MEP-HVAC element	Percentage of wet surface	3D laser scanner	Area affected by humidity according to KPI (1) with respect to the total area analysed [%]
Threshold		Action needed	Action possibly needed	No Action needed
Area affected by humidity (AAH)		AAH ≥ 10%(g)	AAH ≥ 5%(g)	AAH < 5%
(g) Figure based on CARTIF's experience working in close relation to construction companies.				

Figure 197: Sample dashboard Moisture Cartif-3

The applicability of easy to understand balancing dashboards integrated in the software RE Suite is an important added value. Especially for thermal and sound insulation but even for issues like moisture the application at easy level is released -see sample of Cartif-3 above.

Based on the use case approach and the validation of the INSITER methodology performance at demonstrator site level D5.4/D5.5 highlight specifically the foreseen embedded stepwise activities in coordination with close relation to the INSITER application guidelines produced in D1.2 Guidelines for self-inspection in new construction and D1.3 Guidelines for self-inspection in refurbishment. The definitions of the stepwise testing activities related to the INSITER 8 step methodology summarised in this deliverable are connected with an outlook on expected results in order to create thresholds for upcoming and foreseen validation activities on site and a validation of the INSITER methodology as a whole at the same time. These activities are documented in the merged deliverable, now.

The results of life tests are documented in the subchapters of D5.5 Field demonstration report focusing on involving stakeholders in real demonstration cases in every chapter related to the single demonstration site..

The stakeholders – as identified for each demonstrator- have been integrated in the testing and monitoring activities at practical workshops in order to gain qualified feedback on the performance of the INSITER tool and the methodology. All life test results of all demonstrators and related use cases will be cross-case analysed and benchmarked as a final analysis of results and highlighted in D5.7 (as defined in the draft of the revised DoA) Cross-case analysis and benchmarking due at M48. Each demonstrator and the related and assigned use cases have been analysed and validated. The final results of the validation activities are summarized below, specific data are embedded in the chapters related to the demonstrators in this deliverable.

Demonstrator 1: Health Centre Cologne

The Cologne use cases are validated on site and at factory level of the general contractor and the results and the created impact for the contractor involved in the testing actions as an important stakeholder are quite promising.

The technical equipment needed for measurement issues -in this case 3D laser scanning- and data gathering are already successfully introduced and the harmonising of results for balancing them against thresholds is applicable. The deviation analysis is providing extra impact based on the overlay of the BIM model and the as-modelled deviation check.

The QR code scan and use for identification and positioning is applicable and the IFC model transfer and interaction for locating and assigning technical features of components is feasible and proofed at smartphone and handheld level. The important geometry check is validated using 3D laser scan technology and a balancing dashboard analysing the test results by the RE Suite. The RE Suite shows dashboards that are adjustable in terms of client and technology or other individual needs - legislation, norms, regional or country specifics - that will provide an easy to use visualised clash detection report for geometrical accuracy. The augmented reality application supporting the appropriate mounting of components on site is validated successfully, too, and was applied in year 3 and 4 of the project.

Demonstrator 2: Sustainer Homes, Delft

The Sustainer Homes use cases have been validated based on on-site observations. Consequently, the applicability of the implementation of the INSITER methodology has been proved. The technical equipment needed for measurement issues and data gathering has been introduced, integrated in the 8-Steps of INSITER based on the detected on site needs and critical moments following the construction workflow.

The envelope execution facilitating the INSITER mobile app (ref. D4.4) is feasible, while at the same time the required content for self-instruction has been investigated. This reflects construction needs related to detected on site demands and errors leading to energy efficiency shortcomings: as insights from the on-site experience. At the same time, the critical moments when inspection with special equipment is needed has been identified, while how such measurements can be integrated in the overall INSITER methodology has also been described.

The added value of this demonstrator is significant. The monitoring and analysis of the construction process and gathering of relevant material from observations allows drawing connections and conclusions related to the applicability of the INSITER methodology. The cooperation with the general contractor proofed the positive impact of INSITER quality assurance processes and means. Especially the “IKEA guidelines” provided by the general contractor and further developed for self-instruction application and embedded in the guidelines available for workers online and paperless provides extra value helping to overcome quality shortages causing building physic problems at different stages of the mounting process.

Demonstrator 3: Hogekamp in Enschede

In May 2018 within a stakeholder meeting a significant work progress has been achieved as the described use cases of the Enschede demonstrator have been demonstrated to the public on site. Regarding the 1st use case, the visual comparison of the façade panels and windows with the BIM model has been conducted already in November 2017. The thermal scanning was performed in 2018 in synergy with the P2ENDURE project, where thermal sensors and “Comfort Eye” delivering data related to indoor climate data have been installed by UNIVPM to measure the IEQ and to compare the results before and after the deep renovation. Regarding the 2nd use case, clash detection is being performed. The testing of the AR simulations on site has taken place in December 2017 and was presented to stakeholders in May 2018. This demonstrator provides a good example of a large scale validation of the INSITER tools and processes on a real renovation / transformation project.

Demonstrator 4: School Complex Pisa

The use cases for the School Complex in Pisa are validated within the INSITER methodology and can tackle some specific recurring scenarios that occur in the building sector, especially for the existing building stock.

Use case 1 that regards mapping and geometrical check via laser scanning and BIM modelling, started already in 2016 and has been completed in Nov 2017. The geometry check has been validated using 3D laser scan technology, while the BIM model has been used to perform the deviation analysis. Especially the deviation analysis is important for existing sites. On the other hand, during the INSITER project development, use cases 2 and 3 had to be modified and adapted to the new requirements set by the building owner, who opted for the almost total replacement of the facility, with the exception of the gym building. However, this new situation entailed a significant opportunity to develop use cases 2 and 3, which have been carried out in next June / October 2018 to allow the partners that perform on site measurements and AR to make the required procedures, without overlapping with other demo projects. The technical procedures and the tools that will be applied in use cases 2 and 3 have been already defined in other WPs and will be validated on site and then embedded in the INSITER software. The detailed definition of the on-site condition is being defined and tests have been performed at existing building level. Nevertheless, as the client decided meanwhile to demolish the whole building just two use cases are analysed in the D5.5 subchapter.

Compliance with Key Performance Indicators

The geometric consistency and the building thermal performance are two significant Key Performance Indicators to provide information about the energy efficiency of the building. If the existing building envelope presents any irregularities in geometry and/or in thermal properties, the building thermal behavior can be affected and cause energy losses and an increase in the annual energy consumption. The assessment of these KPIs can be used to develop possible refurbishment scenarios, considering the project goals (e.g. refurbishment that also includes an upgrade of the energy label), payback periods and time schedule.

In particular, the thermal measurements can provide information on the actual technical features of the envelope when details/data on the original building components are missing. In fact, thermal maps registered on the building envelope of the demo case in Pisa did not highlight any thermal bridge that is not connected with the different thermal emissivity of the material of the building facade. Nevertheless, the thermal transmittance calculated using the stratigraphy of the wall show that its value (3.8 W/m2K) is higher than the estimated one (1.2 W/m2K). This surplus of thermal transmittance affects substantially the energy performance estimation of the building.

Improvement and lessons learned

The main goal of the demo case was to capture as-is situation of the building envelope and provide refurbishment scenarios to be compared, considering that no information on the building was available except from some 2D drawings.

The building physics analysis (U-value, sound insulation) and the indoor climate analysis was outside the scope of the present demo case, which main goals were to address:

- Poor safety performance of the building envelope elements. In particular, liability of non-structural elements (prefab panels), that could collapse and cause injuries to the building occupants.
- Poor energy performance of the building envelope (prefab opaque panels, U-glasses of skylights, waterproofing layers), due to bad condition.

The first phase of mapping has been developed using INSITER methodologies to improve and enhance standard practices; the second part, i.e. the development of possible scenarios, mainly refers to design and therefore is not included in the INSITER, but the INSITER procedures during on site measurements and off site simulations have speed up the elaboration of different design options.

Thus, AICE (as SME of building inspectors and engineers) has been able to capture the requirements and provide effective design solutions to the Building Owner, based on actual condition of the building envelope.

From the geometric analysis and the calculation of deviation analysis (Use case 1) of this demo case, it has been learned that is not efficient to model on base of point clouds, since this would need too much computing power, because those point clouds are very large and hard to handle. The exactness of the point clouds cannot be transferred into a 3D model and therefore abstractions would be needed (cracks and really minor changes of surfaces are included in the point clouds, but should not be included in a BIM model). In addition, lots of items which are shown in laserscan are not relevant for the BIM model itself – this abstraction makes modelling very hard and time-consuming.

There are approaches to automate the BIM object creation (e.g. for pipes and ducts), but the effort to validate if those items have been correctly been transferred from points to BIM objects, is far greater than modelling the objects on base of 2D drawings. Finally, it has been found that deviation analysis is a great tool to validate the correctness of available 3D data.

From the thermal inspections and the calculation of the transmittances (Use case 2) of this demo case, it has been learned that, according to the test conditions (mainly environmental ones) and the type of the building (new construction or renovation), it is possible to adopt the most appropriate technique and test procedure that allows having the best compromise between expectations, available resources and time. In this demo case, an analysis of the test conditions (season, possibility of conditioning, etc.) and the condition of the building under renovation made it possible to establish that the fastest, least expensive and less invasive method was the drilling coupled with analytical calculation.

Demonstrator 5: CARTIF-3

Use cases 2.1 use case 2.2 have been performed proving the feasibility of the INSITER tools in order to validate the quality of the thermal envelope -building physic analysis- of prefabricated elements and determine geometry checks. In this way, a set of measurements would help the stakeholders during construction and commissioning to detect gaps and errors. Envelopes are usually one of the most critical elements in energy efficiency and, therefore, checking its quality is one of the pivotal steps in the construction process. Thus, by means of 3D laser scanning combined with additional WP2 equipment and related tools, self-inspection methodologies may be applied on-site.

On the other hand, energy systems are also crucial when facing energy performance. In this way, renewable sources are being integrated in buildings. The example for the so important case of solar thermal systems is provided with CARTIF-3 building. The performance of these elements is important to cover the energy demand. Therefore, a proper commissioning and post-commissioning procedure based on self-inspection equipment, monitoring and surveillance (supported by RE Suite dashboard) is quite promising in order to provide a helpfulness method to be validated in the next steps of the project (on-going use case 2.3).

3D laser scanners have been proven the only devices that provide global, accurate (pinpoint) and dense data at once for self-inspection of EE buildings made of prefab components. 3D laser surveying allows measuring geometry discrepancies/deviations between newly designed elements and existing conditions or by evaluating the current situation prior to refurbishment or maintenance operations. A specific KPI for dimensional control for doors and windows is addressed. An innovative practical non-destructive moisture inspection method is ready to be used (TRL 7), based on the study of the reflectivity index. Humidity can be easily detected and displayed on the same 3D point cloud obtained when documenting such a type of buildings, usually made of homogeneous materials. In this regard, two KPIs have been established for moisture detection and assessment.

Point clouds (locally or globally referenced) can engage additional information by combining them with different types of useful 2D imaging (high-res pictures, thermographs, etc.) to be managed into REVIT (as worldwide representative tool) for BIM modelling and project planning.

Furthermore, monitoring and software tools are important means for self-inspection. Despite being mostly part of post-commissioning and operation building stages, they are influential to determine inefficiencies and malfunctioning of energy resources and, therefore, low efficiency of the energy generation systems. This sometimes deals with low energy efficiency of the building, even though the passive elements (e.g. insulation) could provide high-quality characteristics. CARTIF-3 as building in the operational phase framework provides this valuable tool upon two specific KPI for commissioning of solar thermal systems.

Compliance with Key Performance Indicators

KPIs were defined in the WP1 according to the methodologies for building components and HVAC systems, as well as the common errors. In this way, this analysis has followed the definitions from WP1 with the aim of quantitatively determining the building pathologies in contrast to the common errors database.

Compliance with stakeholder requirements

The main goal of the CARTIF3 building was to ensure the proper operation of the building during maintenance phase within the building life cycle. In this sense, some renovation activities were required to improve the energy efficiency of the building and solve the inefficiencies. Mainly, insulation levels of some of the façades were not enough and the performance of the solar thermal system was not as designed. In this sense, the involved stakeholders' requirements are according to the use cases defined at the beginning of the project, where certain pathologies were primarily determined. During this iterative process, the use of tool for self-inspection has helped to contrast the compliance of the stakeholder's requirements.

Improvement and lessons learned

Although it will be part of D5.7, initial lessons learned are focused on the necessity of these analyses of the building performance. Checks and quantitative results help to identify inefficiencies and, thus, detect building pathologies in contrast to the original design of the building. Therefore, the developed tools support the decision-making process from an objective point of view and, then, accurately, obtain the exact construction errors.

Demonstrator 6: Modular building at DRAGADOS factory

Additionally to test carried out at factory level in 2017 by UNIVPM a specific project was identified to be available during the first quarter of 2018. Although the project detailing is under continuous progress, the necessary information was generated during January 2018, giving the INSITER project partners enough time to generate the necessary additional information (AR content, BIM models, etc.) for documentation needs and to prepare the stakeholder meeting at September 2018. The selected use cases to be carried out on that project allowed the partners to receive real feedback from construction workers and other stakeholders about the usability and usefulness of the INSITER tools. One of the most important aspects of this demonstration workshop at the factory was to interact with construction workers and other stakeholders to find out the main positive and negative aspects of the technologies and tools developed.

The analysis of this impact has been done applying a special survey methodology that enables the analyst to qualify and quantify the feedback of stakeholders and rate the specific impact. The results of this analysis are embedded in D5.7 Cross-case analysis and benchmarking. Two of the three use cases are the continuation at a larger scale of tests already carried out on other modules at the factory in year 2 and 3 of the project. Therefore, some of the difficulties experienced on the initial tests are already known and are under control.

The process of validation starting with the creation of storyboards and identified use cases - see D5.3 – and the detailed feasibility check as the final preparation of testing in order to validate the application of the INSITER methodology ends with deliverable D5,4 while the merged report including D5.5 is focusing on the live test results and to analyse them.

Final remarks

The INSITER methodology and toolset has been developed based on high end scientific and industrial knowledge. Measuring and testing processes have been analysed, applied and approved at the laboratory, the factory and the field. The objective was the optimization of the use and the integration for real life testing. As the practical results and the application and documentation have been the focus of WP5 tests at various demonstration sites have been performed. Especially at European level there is a need to involve all stakeholders and receive the feedback from different countries representing the demands of e.g. various geo–clusters, building law and other building cultures influencing the quality assurance of the building process especially if the energy-efficient building sector is the target.

Typology	Dmonstrator	Use case	Device
New construction	Cologne	1 Scan of QR code	QR scanner
		2 Geometry check	Laser scanner
		3 AR application	AR
	Delft	(1 Comparison of the IKEA-like self-instruction manual with the actual situation on site)	X
		2 Identify right moments for visual inspection and inspection with tools	Acoustic measurement
		3 Compare as-designed with as-delivered and as-built situation (overall)	Acoustic measurement
Refurbishment	Enschede	1 Building envelope – Inspection of deviations or flaws at the placement of new facade	Thermal measurement
		2 MEP system – AR on-site simulation	AR
	Pisa	1 Checking of geometric consistency and BIM validation	Laser scanner
		2 Checking of thermal performance on 2D components	Thermal measurement
		(3 Checking of the connection between existing building and additions using AR)	X
Maintenance	Valladolid	1 Check and approval of measured values	Laser scanner, deviation analysis
		2 Building envelope quality	Laser scanner
		3 Commissioning of the solar thermal system	Thermal measurement
Factory	Seville	1 Thermal and air tightness evaluation of the module's envelope	Thermal measurement
		2 Acoustic evaluation of the module's facade	Acoustic measurement
		3 Application and demonstration of INSITER BIM based AR Apps	AR

There is a dilemma in demonstration activities that should cover all the above mentioned aspects and give evidence that the collected results are transferable from a single demo site in one country following just its characteristics to other countries. The practical motivated INSITER decision was to go for the use case approach in order to localise the results and analyse the transferability. Furthermore it was obvious that the embedding of single use cases in the on-going building process on sites is complicated enough - timing, organisation, integration, publication - especially if a research and development project is "harming" the regular approach, at least it is steeling time from the project and the stakeholders involved. Therefore focusing on a full-spectrum of field validation requests a use case oriented organisation.

Assignment and framework based on testing matrix

Nevertheless if the valuable feedback from real sites is targeted providing the most valuable impact one has to compromise and the INSITER solution was to apply the use cases as an easy to communicate and to realise part of the whole application process at different sites and different countries. A single demonstrator would never produce this variety of feedback. Furthermore, the testing has been integrated from the start of demonstration activities following a matrix of assigned use cases and contents that create a holistic picture of all integrative use cases in one application. The measurement techniques and devices that have been used and the processes applied have been composed and integrated from the start of demonstration activities.

INSITER ends at TRL6 and there are on-going activities of the consortium to close the gap between the R&D project and the market demand and exploit the project results –see D6.6 Business Plan. Especially the demonstrator in Enschede is a good sample for a future holistic testing area, where all steps of the INSITER methodology and all technologies to be applied were relevant:

1. Mapping: Collect actual condition of site and building (e.g. 3D Laser scan)
2. Checking: Validate components (e.g. QR code assignment)
3. BIM for on-site construction (e.g. Modeling process integrating mapping results and existing data)
4. BIM based AR application (e.g. AR check application)
5. Clash detection during construction (e.g. AR check of MEP/HVAC systems)
6. Self-instruction (e.g. application of guidelines)
7. Self-inspection (e.g. thermal scanning, sound insulation measurement)
8. Final check (e.g. pre-commissioning preparation)

Even in this sample driven by practical decision making on site the efficiency and effectiveness of the single process step used and the influence on decision making for techniques applied is Important to clarify the relevance of the application for the characteristic case. As shown in the matrix above all of these samples applied in single steps have been tested at different sites and the applicability is proofed.

The real energy consumption (in kWh) can only be measured in the occupation phase that follows the construction phase. During the construction phase, we can measure the deviations in energy-related properties of the building parts. For example in Delft case, we performed measurement and calculation during addressed the construction process which showed the R/C-value or U-value of the building envelopes. The estimate of energy consumption can be calculated using the method described in D1.5, but the actual energy consumption in building operation is not measured as it is out-of-scope of INSITER.