Best practices and existing shortcomings

Deliverable report 1.1

Deliverable Report D1.1, 2nd revision after EC review, issue date on 30th of May 2016

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.

Best practices and existing shortcomings

Deliverable report 1.1

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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.

Fulfilment of the Description of Action (DoA) in D1.1

Accessibility of this deliverable

This deliverable is presented in 1 part:

- Report / documentation (this document)

Fulfilment of WP, Task and Deliverable scope and objectives

Summarised objectives as stated in DoA	Results presented in this deliverable
WP 1 scope and objectives: - Key performance indicators (KPIs) and parameters addressing quality and energy performance - Techniques for self-inspection and self-instruction in different types of projects (new construction, refurbishment, commissioning, and maintenance).	**Addressed:** - The deliverable presents (see chapter 4) a set of KPIs for building quality and energy performances. For each KPI the deliverable provides: description, explanation, measurement parameters, and technical references. The KPIs selected will be tested on the INSITER Use Cases and evaluated through the quantitative methods of the protocols (action on-going); - The deliverable includes the description of the general aspects of techniques for self-inspection and self-instruction as well (see chapter 2 and 3). **Not addressed:** - Techniques for self-inspection and self-instruction will be analysed with more details when the next steps of the WP2, 3 and 4 will completed and the results available; - Techniques for self-inspection and self-instruction will be validated and tested on specific projects after the implementation of the “Test Cases”.

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Task 1.1 scope and objectives:

- Lessons learned from the past-performance studies and evaluations, actual directives, guidelines, etc.
- Self-inspection addressing organisational and legal conditions for collaboration; feedback mechanism from implementation to design.
- Mapping of specificities of new and existing prefab-based EeB, including monuments / cultural heritage.
- Methodology concerning process, actors and instruments (systems, devices, etc.) for self-inspection and self-instruction.
- Generalisation of INSITER solutions for prefab buildings to other building typologies.

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Addressed:

- The deliverable presents (see chapter 2 and Appendix 1-2) a selection of EU technical standards for building assessment most relevant for INSITER, the current practice of building inspection (introducing the case study of Dragados), the current shortcoming and the potential improvements of the building inspection procedures.
- The deliverable identifies the building components and MEP-HVAC systems of prefab buildings for which the most frequent construction errors on-site can be crucial for their energy efficiency (see chapter 3).
- The deliverable implements a first draft of the innovative INSITER protocol (see chapter 5) and describes the building process of prefab buildings (see chapter 2). The implementation of the INSITER protocol is on going and will be completed with D1.2 and D1.3 (M36).

Not addressed:

- The detailed map of characteristics of new and existing prefab Energy efficient Buildings will start in the second year and will be based on the analysis implemented in this deliverable, worked out on: norms, directives, standards and construction errors. Furthermore it was not started since it is needed the input form the demonstration cases proposed in the WP5.
- The generalisation of the INSITER solutions to different typologies of building will be defined with the INSITER guidelines at M36 (D1.2 and D1.3).

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Deliverable D1.1 scope and objectives:

- Critically reviews the state-of-the-art procedures
- Describes innovative ways for self-inspection, quality assurance and energy-performance check.

</td><td>**Achievement:**</td><td>**Percentage:**</td></tr>
<tr><td>- Critical reviews (SoTA) of building inspection, procedures and process.</td><td>100%</td></tr>
<tr><td>- Innovative self-inspection procedures, building quality and energy performance.</td><td>100%</td></tr>
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Project's progress relevant to the deliverable within the corresponding timeframe (Year 1):

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- Clear identification of existing bottlenecks, most frequent errors, and shortcomings in skills in the construction processes across the EU. Such identification is based on reliable and up-to-date investigations (e.g. Dutch "Bouw Transparant", UK "Constructing Excellence", and similar reports from Germany, Spain and Italy).	**Achievement percentage:** 80% **Explanation:** The most frequent construction errors of prefab buildings and existing shortcomings or bottlenecks have been defined and presented in this deliverable. Despite this, the research will be continued even more in the next months in order to complete the overview regarding the application of specific MTTs inside the building process in cooperation with WP2, WP3 and WP4.
- Critical review of process, performance, and inspection norms (e.g. Dutch norm NEN 2767 on condition assessment, Energy Performance Coefficient norms)	**Achievement percentage:** 90% **Explanation:** The main EU inspection norms and performance standards have been collected and presented in the deliverable. The work could be improved in the next months to propose the application of the collected norms inside the INSITER methodology.
- Definition of plausible KPIs	**Achievement percentage:** 100% **Explanation:** The main Building Performance, Project management and INSITER's effectiveness KPIs have been presented in this deliverables (see chapter 4).
- Calculation methods for performance assessment as well as self-instruction	**Achievement percentage:** 40% **Explanation:** The main MTTs to measure the KPIs and parameters have been introduced in D1.1 and other WPs. The activity is ongoing and will be defined in detail in the next D1.4 (on building component) and 1.6 (on MEP-HVAC system).

Addressing the EC remarks 01

Status	Date: 04-03-2016 Status: Rejected EC Project Officer: José Riesgo Villanueva EC Expert: Gabriele Willbold-Lohr

Summarised of EC remarks	As described in the DOW, p 13, “it is a result from task 1.1 and it critically reviews the state-of-the-art procedures and describes innovative ways for self-inspection, quality assurance and energy-performance check”. The deliverable is well presented however any critical statements and conclusions are missing. The focus of INSITER is on building construction with prefabricated elements, however the information in the deliverable is very general descriptions of current practices and technologies. A clear focus is not fully visible. The building process is described too general, is SoA and is not specially focussed on building with prefabricated elements. And it does not link the anticipated self-inspection and self-instruction with the standard building procedure. There are long lists with errors in the building process, however not further analysed and differentiated. The most common failures/most frequent failures are not elaborated and substantiated towards the goals of the project. It is also not made clear to what extent the results presented in the deliverable contribute to the development of the methodology and the tools in INSITER. The deliverable would benefit from a clear and focussed structure and specific analysis and conclusions. Some aspects of the foreseen subjects/activities of task 1.1 in WP1 are not fully reflected in the deliverable. Content not fully in line with GA part B.
Implemented measures / solutions / improvements	Major revision of the deliverable: - Changed: a new structure reflected in a new Table of Content - Added: summary of how this deliverable addresses the DoA and EC’s remarks - Added: decisions on preliminary KPIs and their positioning within a multilevel framework comprising KPIs, parameters, references, etc. - Added: critical reviews of the current practice for inspection (building technical assessment) - Added: conclusion on an outlined ‘storyline’ of the INSITER innovative way for self-inspection and self-instruction, for further elaboration into practical guidelines and use cases in the follow-up deliverables (D1.2 and D1.3)

INSITER INTUITIVE SELF-INSPECTION TECHNIQUES

Addressing the EC remarks 02

Status	Date: 04-05-2016 Status: Rejected EC Project Officer: José Riesgo Villanueva EC Expert: Gabriele Willbold-Lohr
Summarised of EC remark	**Remark 1:** Although this deliverable has undergone quite some alterations, it does not clearly present the new approach of INSITER as stated in WP1: it critically reviews the SoA procedures, and describes innovative ways for self-inspection, quality assurance and energy-performance checks **Remark 2:** The listing of building component standards in Appendix 1 is meagre considering the European approach and the huge amount of standards related to building construction. The listing of the German standards comprises 25 standards, which are on top duplicated by cut and paste on the last page.

Implemented measures / solutions / improvements (for remark 01)	Actually, the previously revised and resubmitted deliverable D1.1 has already addressed these 2 topics comprehensively:

- “Critically reviews the SoA procedures” >> has already been addressed in:
    - Chapter 2: Critical review of performance assessment and quality assurance in the current practice. Real examples from the current practice were also presented (on pp.44-47), and the existing shortcomings were discussed (on p.47 onwards).
    - Chapter 4: Most frequent construction errors {in the current practice}. An extensive list and description, derived from both own experience of construction and engineering firms in the INSITER consortium as well as professional literature and database, has been presented in this chapter.
- “Innovative ways for self-inspection, quality assurance and energy-performance checks” >> has already been addressed in:
    - Explanation of the required innovative ways, presented on p.50 (last paragraph) until p.56 (first half).
    - Description of the [innovative] INSITER protocols in Chapter 5.
    - Consolidation of the [innovative] Key Performance Indicators for self-inspection in Chapter 4 (it was Chapter 3 in the previous version).

However, it seems that the written presentation of the deliverable content was not optimal, so it is not easy for a reader to access the valuable knowledge contained in the report.

Therefore, we make <u>the following improvements to this deliverable to meet the EC’s recommendations:</u>

a. Restructuring of the report to directly reflect the 2 main topics:

Improved deliverable structure	**Explanation of change**
1. Introduction	Added explanation in Subchapter 1.2 that this report is mainly structured with two main parts (Chapters 2+3 on ‘review’ and Chapters 4+5) on ‘innovation’).
2. Critical review…	These two chapters together represent the critical review of SotA procedures
3. Most frequent errors… (it was Chapter 4 in the previous version)	
4. Proposed KPIs… (it was Chapter 3 in the previous version)	These two chapters together, including the additional contents, represent the innovative ways for self-inspection.
5. Innovative INSITER protocols… ADDED CONTENT: - Text on pp.40-43 in the previous report version presented as Subchapter 5.a - An elaborated table of the innovative INSITER 8-step methodology added to Subchapter 5.1.1 - Change in numbering of previous Subchapters	
6. Follow-up	No change required.

b. Inclusion of an elaborated table of the innovative INSITER 8-step methodology added to Subchapter 5.a (this table is derived from the DoA and extended after research in Y1 – see figure below)

Step	Activity	New construction	Major refurbishment	Planned / key maintenance
1	**Mapping existing building or building parts/systems**	N/A except for building site; starting point is design	Mapping / assessment of existing building; outcomes integrated in 'refurbishment design'	Assessment of existing parts/ systems (e.g. roof, HVAC); outcomes integrated in 'maintenance action plan'
2	**Verifying design and prefab components**	Verifying construction / refurbishment / maintenance plan; verifying the specs of selected prefab components according to design / maintenance solutions		
3	**BIM creation**	BIM design model	BIM models of existing and refurbished building	BIM models of the building or MEP systems subjected to maintenance
4	**Virtual (BIM) validation**	Clash detection; interfacing BIM with software / AR app		
5	**Creation of self-instruction guidelines**	Step-by-step guidelines for construction / refurbishment / maintenance visualised in 3D based on BIM model(s)		
6	**On-site preparation**	Positioning BIM / integrating building site in BIM; verifying ordered and transported prefab components, on-site logistics, cost and time schedules		
7	**Quality validation during on-site processes**	1. Workers watch step-by-step 3D self-instruction on their mobile devices 2. Workers perform the instructed activities 3. Workers compare their own results against 3D model using AR, and send report to Supervisors 4. Supervisors analyse the results online and give approval or request for repair/rework 5. Supervisors evaluate the process and possible implications (e.g. risks, delays, budget overrun)		
8	**Performance validation of the realised building**	1. Take thermal / acoustic / geometric measurements of the realised building or room 2. Analyse the KPIs, compare actual vs. designed to determine whether or not there is a gap 3. Give feedback to on-going on-site processes and/or to design		

Implemented measures / solutions / improvements (for remark 02)

a. The presented list is <u>a short listing</u> resulting from deep analysis of the most relevant technical norms / standards / codes / papers / books / thesis that can potentially utilised or adapted for self-inspection. We do not have the intention to present all references, but we are focusing on the INSITER purpose for self-inspection.

We started with research comprising app. 350 references on: Design and construction process, Inspection procedures and standards, Inspection equipment, Building construction errors, Other useful documentation, Norms/Directives. We analysed them, and concluded the most relevant ones in the short listing presented in D1.1. The most part of the documents analyzed can be found on the project website Sharepoint through this link: INSITER WP1 REFERENCES (1).

The consolidation and analysis of these long list was effort-intensive and time-consuming. This is part of the justification of the amount of real time/resource spent in WP1 during the first year.

b. Indeed there is an unintentional duplication in the list of the relevant German standards (due to error in exporting the table from Excel to Word). We appreciate the EC Reviewer's notification of this mistake, and we have fixed the table.

(1) Link to WP1 References on the Sharepoint:
http://www.insiter-project.org/Shared%20Documents/Forms/AllItems.aspx?RootFolder=%2fShared%20Documents%2f07%20WP1%2fWP1%5fReferences&FolderCTID=0x012000C2A304B4D90D9040A6CB656C2EE845CA&View=%7b6E9E3FDF%2d936F%2d48F4%2d9D22%2dA1971DF3C0F1%7d

Publishable executive summary

According to the strategic objectives of WP1 – the development of a main process framework for self-inspection and self-instruction techniques in the construction and after-construction process – and specifically to those ones to be achieved in Task 1.1, this deliverable aims to critically review the State-of-the-Art and to describe innovations in the self-inspection procedures, quality assurance and energy-performance checks.

Along with a detailed description of the methodology employed to implement the report, the Introduction includes (pag. 23) a mind map that offers a clear picture of the structure that the contents and the rationale of the deliverable are based on. The expected results have been reached through:

- the definition of a common framework of the building process focused on the specificities of prefab technologies;
- the identification and description of the main actors involved in the building process;
- the current inspection methods, the European standards that those methods are regulated by, the shortcomings and the innovations that can bridge the existing gaps;
- the definition of the Key Performance Indicators (KPIs) to be used for measuring the performance of the crucial topics like: energy efficiency, building quality, managements quality, etc.;
- an inventory of the common construction errors that can be found with new self-inspection methods proposed by INSITER and the critical building and MEP/HVAC components to be inspected.

Finally the report includes a first "preliminary" INSITER protocol based on the eight steps self-inspection methodology described in the research work programme.

The implementation of the first three matters of the above-listed ones has been a crucial task in the development of Task1.1.

It has been absolutely needed to define and to share a common approach to those issues – as well as the construction process applied to the prefab technologies, the profiles of actors and stakeholders, the inspections methods – characterized by relevant variances depending on the different conditions of the construction market in the different Countries (especially after the profound and long lasting crisis on the building sector).

Due to this reason the analysis implemented in Chapter 2 takes up a significant part of the report.

The building process and the key persons involved

With the aim to define a common understanding of the "**building process**" and considering focus and goals of INSITER, the RIBA Plan of Work has been taken up as the more suitable framework. The leading pros of **the RIBA PoW 2013** are represented by its clarity, easiness and flexibility; the cons are its "design oriented" approach and some missing aspects related to the construction and manufacturing building stages.

The process proposed is organised in nine main tasks. The tasks consider the entire "building life cycle", excluding the demolition phase due to the fact that it is not relevant to INSITER.

The nine tasks proposed are:

1. Concept design;
2. Detail design;
3. Final design;
4. Pre-production phase;
5. Factory production phase;
6. Transportation to site;
7. On-site assembly phase;
8. Commissioning;
9. In use and Maintenance.

The report describes each task in detail introducing the main task objectives, actions and outcomes to achieve the expected results.

A number of **key persons** characterize the building process. Section 2 defines these roles in a more strict view of the "INSITER construction process", meaning from the perspective of prefabrication, together with the aim of self-inspection during the construction process in order to achieve the expected building quality and energy performance. The key persons are classified as follows:

- Principal / owner (professional and non-professional);
- End-users (with facility manager and without facility manager);
- Project manager;
- Advisers/project team (architect, BIM manager, structural engineer, MEP-HVAC engineer / building physics engineer / energy consultant);
- Construction workers / installers;
- Production/manufacturing workers.

All the key persons are analysed and described on three different levels to better highlight and understand their (new) roles when prefabrication and self-inspection (sometimes in combination with self-instruction) are imposed on the traditional building process. These three levels are: (1) traditional building process, (2) prefabrication building process and (3) quality self-inspection.

In the last years the introduction of **BIM** has proposed a significant influence on prefabricated buildings and it has improved project communication quality among all actors involved in the process.

BIM proposes a new quality management plan of the construction. The quality control process begins with quality management plans based on the design drawings and specifications, which establish the quality of the material and equipment, the accepted criteria for the work in place and the inspection and testing to be performed.

The project manager, construction and production workers monitor all work and identify deficiencies (errors) beyond tolerable limits. Upon completion of the work, inspection and validation testing is conducted to verify compliance with the requirements of the approved construction documents.

In general, the control of quality in a construction project consists of field inspections that guarantee that workmanship, physical properties, equipment and material supplied by the contractor are in line with the final design and specifications.

Considering the INSITER scope we can assume as **key stakeholders**:

- **Manufacturer** that plays an important role from design, to production, to assembly of the elements on site and the guarantee systems. The role of the manufacturer changes from supplier (of elements) to co-maker or even to contractor. This influence the traditional roles in the building process in a great deal. Production workers and assembly workers determine the quality of the product and are responsible for the self-inspection.
- **BIM manager** as the hub of development and communication activities (multiple directions!), including translation of self-instruction guidelines to hand-on digital tools. The model should give a complete overview of all the quality checks on detail level and on the total building.
- **End-user** as the key person who assesses and tests the final perception of the quality performed by the building.

Building Inspection: current practice, standards, shortcomings and innovations

The building quality is a criterion that influences customer satisfaction with regard to the performance of construction projects.

Inspection is one of the most essential processes in quality control. It is the act of measuring or carefully examining a product's quality and preventing defects to assure that the final product meets specifications and fulfils the customer's requirements. Moreover, effective quality inspection can avoid the very large costs and delays that are associated with re-doing the work.

Generally, quality inspection can be performed during the work-in-process and end-product stages. During the work-in-process stage, inspection is used to check work preparation for each work procedure to reduce the number of defects in the final product. On the other hand, inspection during the end-product stage aims to detect defects or construction errors that must be repaired to improve the quality of the final construction product, including aesthetic issues in architectural work. Therefore, inspection during both stages is essential to control quality and to ensure that the quality of the end product meets the customer's requirements *[C. Laofor, V. Peansupap / Automation in Construction 24 (2012) 160–174 163].*

Focusing on industrialized processes and prefab-based buildings we have to consider the practice of producing construction components in a manufacturing factory, transporting complete or semi-complete components to construction sites, and finally assembling these components to construct buildings. Compared with conventional construction technologies, prefabrication provides controlled conditions for bad weather and for ensuring quality, facilitates the compression of project schedule by changing workflow sequencing, and reduces the waste of materials *[J. Hong et al. / Journal of Cleaner Production 112 (2016) 2198e2207].*

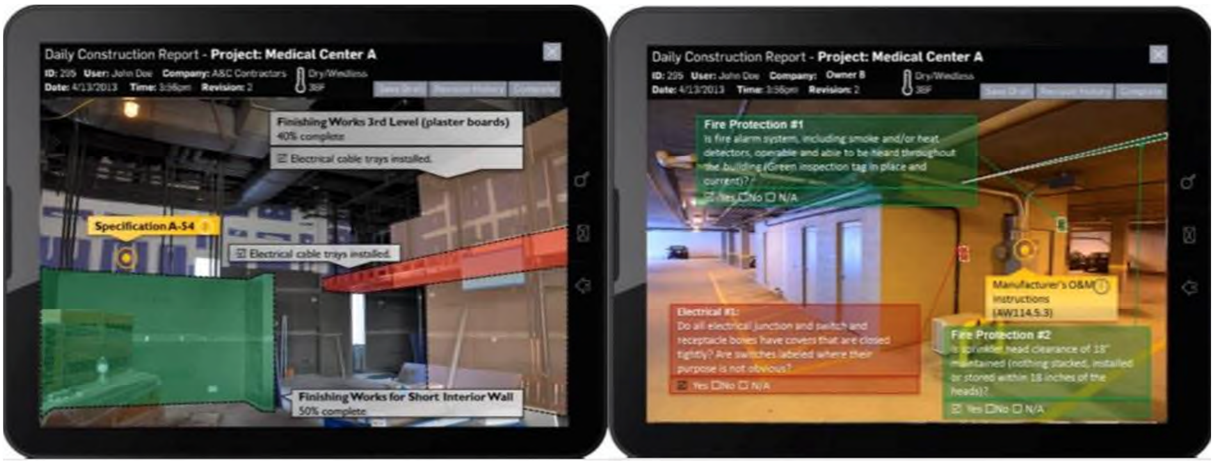
Despite this, the **inspection procedures** and guidelines to evaluate the building quality and the energy performance are generally scheduled when the building is constructed or in-use.

Some important limits of the current "building inspection" methods are:

- high level of subjectivity, which demand technical inspectors with individual experience to reduce the different perceptions without a uniform standard (e.g. the same person might even make different judgments on different days);
- high costs and time consuming;
- difficulty to determine all construction faults, it is not possible for a person determine all possible defects;
- lack of data storage and management systems, a person's ability to judge aesthetic faults is limited in that it cannot quantify the value of a given defect.

Building Inspection: shortcomings and innovations

The actual **shortcomings** introduced denote that the construction sector (new building, refurbishment and maintenance) requires new standards to monitor in real time the performance assessment and building quality. Moreover, it is very important to plan progressive technical checks since the early stages of the decision-making process to prevent and normalize the risk of construction errors. For this reason, it is important to promote the use, during the main tasks of the process, of smart technologies able to communicate "quickly" and in "real time": 1) the building quality, 2) the presence of damage and/or 3) performance not in line with the project objectives. Effectively, the continuous monitoring in real-time (using for instance smart sensors) allows you to identify the construction problem or defect before it is visible, making more timely repairs, reducing the costs and above all increasing quality. Furthermore, integrating Virtual Model (realized using BIM software) and the Augmented Reality in the inspection process, it is possible visualize "intuitively" all data information collected regarding the technological systems analysed. For example, pointing our devices (tablet, smartphone or smart glasses) into a specific part of building we can immediately see any problems.



PAR Works' Mobile AR app, by researchers at the University of Illinois, allows users to geo-tag elements on a building site in real-time, and call up relevant specifications or information pertaining to any building component directly on site. The portable mobile display acts as an interactive 'Site Diary' for its users, and is accessible both on and off the project site. The app allows daily reporting and retrieval of information, online as well as offline.

The main interesting subject of the INSITER innovation will be the general contractor and sub-contractors that can see the construction quality during the manufacturing but also in the entire building lifecycle.

Other important categories are: site supervisor, technical expert, clients and building occupants. Nevertheless, indirect stakeholders may also be insurance companies. INSITER promotes a new concept of self-inspection, which is very different to the current practice and can be summarized: “prevention is better than repair”.

Main shortcomings	Main potential improvements
1. The inspection procedures are scheduled when the building is constructed or in use (See POE).	1. To use smart technologies able to inspect “quickly” and in “real time” during all process stages.
2. The manual-visual inspection is characterized by a high level of subjectivity, high costs and time consuming.	2. To reduce the subjectivity level, costs and time of the inspection proposing the use innovative tools available on the market.
3. The manual-visual inspection does not detect all construction errors.	3. To integrate Virtual Model and Augmented Reality technologies in the inspection process.
4. The actual inspections denote lack of data storage and management systems.	4. To detect construction errors using computer/device vision and image-processing.
5. The existing inspection guidelines are insufficient or not fully useful for the purpose.	5. To elaborate new self-inspection guidelines able to use during the construction process.

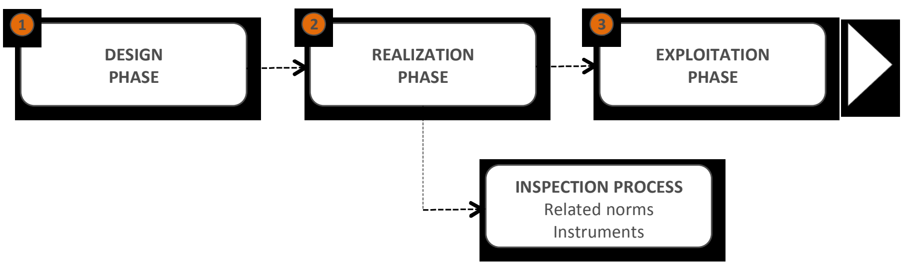
Building Inspection: standards and norms

A detailed overview of available **standards** and **norms** dealing with condition assessment and quality inspection norms is provided in the section 2.5 “Relevant technical norms for building technical assessment”.

INSITER will develop procedures to benefit construction workers in dealing with the inspection processes and timely detecting of construction defects. The new self-inspection process will be adapted to the whole construction process. For this purpose, existing condition assessment and inspection norms need to be inventoried.

Due to the large number of norms, condition assessment will be discussed in general; only relevant norms will be listed. Some inspection processes require using inspection instruments; in that case those instruments will be listed as well.

The collected standards will serve as an input and reference for the INSITER guidelines that are to be developed throughout the project and will be presented in the upcoming deliverables of WP1 of the INSITER project. The collection of the standards was a joint effort of the project partners, however, only the standards from the main contributing countries were selected, that being the Netherlands, Italy, Spain and Germany.



Insiter focus is related to the building inspection “on-site” during the building construction. The norms and standard are very important to compare the building performance with quality standard and to define if the defect level is acceptable or not acceptable.

Section 2.5 presents a selection of standards relevant to the INSITER project and related to self-inspection during the assembly phase of prefabricated building components. A subdivision has been made between:

- Condition assessment and inspection norms and methods for “building components”
- Condition assessment and inspection norms for “MEP-HVAC components”.

Norms and standards are analyzed in more detail and their main contents shortly described, followed by a wrap up of important aspects to be taken up in the INSITER guidelines.

The Key Performance Indicators

The functionality of the KPI-approach is one of the most popular and valuable tools used to measure the performance of several topics like: energy efficiency, building quality, management quality, etc.

In INSITER three types of Key Performance Indicators are used:

1. **Building Technical Quality** KPIs regarding the performance of the building itself, e.g. Indoor Environmental Quality, Energy Performance;
2. **Management Quality** KPIs regarding project management performance in terms of Budget and Costs, Organization, Planning, Information, Quality;
3. **INSITER Tool** KPIs, regarding the effectivity and effectiveness of the INSITER methodology.

Building technical KPIs

The building technical Key Performance Indicators “say” something about the performance of the building itself, e.g. air leakage, sound insulation, regarding building quality as well as energy performance. These KPIs are relevant for the decision making whether the building fulfills its technical requirements, and if not, to what extent an omission leads to decreased energy performance or cost and time increase due to necessary rework. The measurements of these KPIs are strongly dependent on the hardware monitoring tools and BIM, developed in WP2 and WP4 respectively.

Management quality KPIs

In the construction report of the KPI working group of the Minister of Construction of the UK under the headline of “Rethinking Construction” a discussion about the set up of ambitious improvement targets was raised in order to enhance the common quality of construction efforts. The idea was to challenge the building industry to measure its performance over a range of activities and to meet with a set of ambitious improvement targets. From the perspective of the client the projects should be delivered: on time, within budget, free from defects, efficiently, right first time, safely and by profitable companies. The measurements of these KPIs are strongly dependent on the software monitoring tools and BIM, developed in WP3 and WP4 respectively.

INSITER Tool KPIs

The INSITER Tool KPIs "say" something about the self-inspection & self-instruction and show whether INSITER self-inspection/self-instruction does bring added value in comparison to the 'traditional' way of working without self-inspection/self-instruction. Based on these Indicators the stakeholders can decide on the approach they want to adopt for their project: the traditional way or the INSITER way. The measurements and validation of these KPIs are strongly dependent on the factory and site validation and demonstration, as well as training, developed in WP5 and WP6 respectively.

Common construction errors

In order to develop an innovative INSITER methodology the most frequent errors committed during the construction phase of the process (on-site) have been identified. Despite this, analysing the complete design and construction process it is possible to define several errors not only related to the construction task. Nevertheless, INSITER supposed that all "design tasks" are completely perfect (no errors are committed).

With the purpose to identify and analyse the most common and frequent errors a subdivision of the building systems – focusing on prefabricated building types – into levels of the construction or into individual components has been implemented.

The classification of building elements is an integral and key component of some national standards (UNI 8290 - part 1 and 2 in Italy, ASTM E1557-97 in the U.S.), even if there is a lack of common European standard that could provide a point of agreement on design elements for all project stakeholders. According to the both building technology state-of-art and the aforementioned standard references, two main different classifications of building elements can be defined.

Two levels of classification have been considered useful for the INSITER purposes.

A first level of classification is based on the subdivision of the building into: systems, sub-systems, modules and elements, following a hierarchical structure.

Distinguishing the modules of a building is simple, as long as the separation of functions reflects separated modules that are assembled from individual elements. In this perspective, the whole building has been subdivided into:

- **Systems:**
    - Primary systems, consisting of load bearing walls or the structural frame of the building, decks/slabs;
    - Secondary systems, consisting of the building envelope (façade, walls, ceilings, roof and floors).
- **Modules:** façade modules, windows, doors, stairs, roof systems, etc.
- **Elements:** façade panels, glass panes, windows frames, roof beams, etc.

Each major group of elements can also be subdivided into more detailed groups.

The second level of classification is based on design/construction work packages. Elements, as defined here, are major components common to most buildings.

Elements usually perform a given function, regardless of the design specification, construction method, or materials used, as follows:

- **Load bearing elements;**
- **Building envelope;**
- **Interior Systems;**
- **MEP-HVAC Systems.**

Based on the latter four classes, a list of most common errors, focused on those ones specifically referred to prefab buildings and more undermining the building energy efficiency, is listed, described and analysed in section 3.2.

Self-Inspection Protocols

Within the implementation of self-inspection protocols to prevent and detect errors in prefab buildings, the framework of the "eight step self-inspection methodology" in construction and refurbishment, as outlined in the research programme, has been developed.

The eight steps are:

1. Mapping actual technical conditions of the site and building, and performing economic valuation of the property and land; capture the requirements and compare them to as-is situation;
2. Self-inspection at procurement, production and delivery of prefab components;
3. Modelling of the [existing] building, site and surroundings in Building Information Model (BIM);
4. Generating and deploying BIM-based Augmented Reality (AR) for self-instruction and self-inspection;
5. Virtual validation of quality and performance by BIM Model Checking and Clash Detection; as well as value and process optimisation by Virtual Reality simulation;
6. Self-inspection and self-instruction during preparation of construction site and logistics;
7. Self-inspection and self-instruction during construction / refurbishment / maintenance process;
8. Self-inspection and self-instruction during pre-commissioning, commissioning and project delivery.

A clear pictures at pag.98-99 show how the steps are interrelated and which information, data and technical specifications will be implemented in the development of the WPs and Tasks during the next three years of activity.

List of acronyms and abbreviations

- **AEC:** Architecture, Engineering and Construction
- **AR:** Augmented Reality
- **BIM:** Building Information Modelling
- **BLC**: Building Life Cycle
- **DoA:** Description of the Action
- **DoW:** Description of the Work
- **EeB**: Energy efficient Buildings
- **HVAC:** Heating, Ventilation, Air Conditioning
- **ITP**: Inspection and Testing Plan
- **KPI:** Key Performance Indicator
- **LCA:** Life Cycle Assessment
- **LCC:** Life Cycle Cost
- **MEP:** Mechanical, Electrical, Plumbing technologies
- **MTTs:** Methods, Tools and Tecniques
- **nZEB:** Nearly Zero Energy Building
- **PMV:** Predicted Mean Vote
- **PoW:** Plan of Work
- **PPD:** Predicted Percentage Dissatisfied
- **QC:** Quality control
- **STI:** Speech Transmission Index
- **TCO:** Total Cost of Ownership
- **ZEB:** Zero-Energy Building

Definitions (alphabetic order)

Building

The building is a system that includes several functional areas and technological systems. Relationships, interdependencies and functional aggregative configurations between functional areas depend on the characteristics of the building.

Building contract

The contract between the client and the contractor for the construction of the project. In some instances, the Building contract may contain design duties for specialist subcontractors and/or design team members. On some projects, more than one Building Contract may be required; for example, one for shell and core works and another for furniture, fitting and equipment aspects.

Component

The components (both the building and the MEP components) are included into a **"**not spatial level" necessary for the implementation of data for the BIM model.

Construction strategy

A strategy that considers specific aspects of the design that may affect the buildability or logistics of constructing a project, or may affect health and safety aspects. The Construction Strategy comprises items such as cranage, site access and accommodation locations, reviews of the supply chain and sources of materials, and specific buildability items, such as the choice of frame (steel or concrete) or the installation of larger items of plant. On a smaller project, the strategy may be restricted to the location of site cabins and storage, and the ability to transport materials up an existing staircase.

Health and Safety Strategy

The strategy covering all aspects of health and safety on the project, outlining legislative requirements as well as other project initiatives.

Initial project brief

Preliminary task of the process that defines the project's spatial requirements and outcomes. During this task is important: to define the state of the art analysing best practices case similar to the projects; to estimate the budget; to collect the site information including building survey.

Key Performance Indicator

Key Performance Indicator is a quantifiable output measure, agreed upon beforehand, that a can be used to estimate or compare performance of buildings or (sub)-systems.

Maintenance and Operational Strategy

The strategy for the maintenance and operation of a building, including details of any specific plant required to replace components.

Post Occupancy Evaluation

Evaluation undertaken post occupancy to determine whether the project outcomes, both subjective and objective, have been achieved.

Project Execution Plan

The project lead and lead designer will elaborate the Project Execution Plan, with contributions from other designers and members of the project team. The Project Execution Plan sets out the processes and protocols to be used to develop the design. It is sometimes referred to as a project quality plan.

Project program

The overall period for the design, construction and post- completion activities of a project.

Schedule of Services

A list of specific services and tasks to be undertaken by a party involved in the project which is incorporated into their professional services contract.

Sustainability strategy and aspiration

Definition of the specific level of performance expected to the project in relation to international standards (LEED, BREEAM, HQE, DGNB, etc.). This strategy will include items related to the LCA of the building, to the energy performance and ecology plan.

Technology and Communication Strategies

The strategy that sets out when the project team will meet, how they will communicate effectively and the protocols for issuing information between the various parties, both informally and at Information Exchanges.

Contents

1. Introduction

1.1 Objectives and structure of this deliverable

The main objective of the deliverables is to present a critical review, State-of-the-Art and potential improving regarding the following three topics:

1. **Building process of prefab buildings**, proposition of a building process applied to the coming activities of the research;
2. **Energy efficient prefab buildings,** introduction of Key Performance Indicators (KPIs), main technology systems and frequent construction errors;
3. **Inspection methods,** proposition of innovative way for the quality assurance and energy performance evaluation.

The deliverable is organized in six main sections based on the mind-map proposed in *Fig. 1*. Each section introduces different topics related to each other as it follows.

- **Section 1** introduces the deliverable's objectives; the structure of the main contents and relations; the methodology adopted to achieve the results presented and the research limit.

- **Section 2** introduces the general building process adopted by WP1 to analyse the prefab building manufacturing and the main actors involved in the process. For each process task has been defined the current inspection methods meant to present the shortcomings and potential improvements. Last important content regards the presentation of the European relevant technical norms for building technical assessment.

- **Section 3** introduces the INSITER KPIs reflecting the project goals. The functionality of the KPI-approach is one of the most popular and valuable tools used to measure the performance of several topics like: energy efficiency, building quality, management quality, etc.

- **Section 4** introduces the technology systems of prefab buildings as focus of INSITER. The chapter presents the common construction errors that can be individuated with new self-inspection methods proposed by INSITER.

- **Section 5** introduces the “preliminary” INSITER protocols presenting, step-by-step, the main stages of the building analysis on-site in order to achieve the expected results, in comparison to the building technological standard, design performance and, last but not least, owners needs.

- **Section 6** introduces the follow-up research and developments regarding reccomentadion for: the implemenataion of quantitative methods, practical guidelines and tool enhancements to support the INSITER protocol.

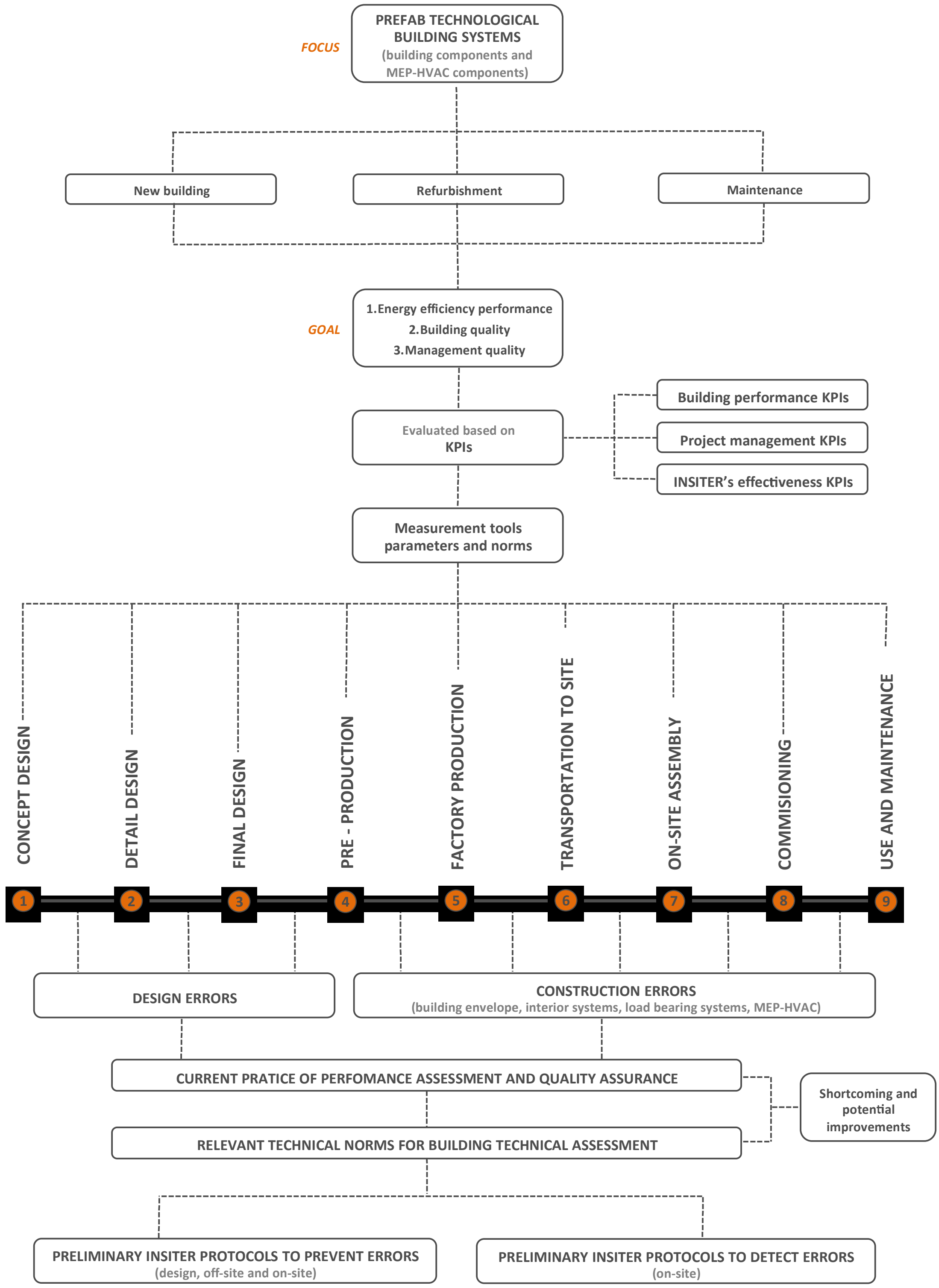
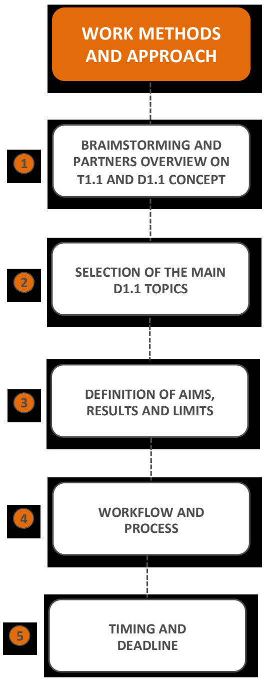


Fig. 1 – D1.1 mind map and structure

1.2 R&D methodology employed to achieve results presented in this deliverable

The first action, inside task 1.1 (starting at the kick-off meeting in Delft), concerned the following work approach.



In five main tasks, as show in *Fig. 2*, the partners have planned the work to do in order to complete in time (M12) *Deliverable 1.1: Best practices and shortcomings* regarding the following two main topics:

- Building process;
- Building inspection.

The five tasks have regarded in detail the following aspects:

1. **Brainstorming and partners overview** in order to harmonize the D1.1 vision of the multidisciplinary team involved;
2. Selection of the main **research topics** of D1.1;
3. Definition of the main **aims and results** aligned with the DoA;
4. Elaboration of a **workflow process** in order to achieve the results;
5. Definition of **planning and deadlines** to close D1.1 at M12.

Fig. 2 – T1.1 work methods and approach

Based on the approach proposed, the task leader has organized a methodology of work summarized in *Fig. 3*.
The research began with a review of the literature and field observations on the selected topics:

- Building process;
- KPIs;
- Construction erros;
- Building inspection;
- Insiter protocols.

Three notes:

1. The definition of the most frequent errors (see chapter 3) is based on the experience and background knowledge of the following partners: 3L, AICE, Dragados, DWA, IAA and ISSO.
2. The action on the elaboration of the INSITER protocol with the definition of specific use cases is proposed in synergy with WP2, 3, 4 and 5. This task is ongoing.
3. The report is mainly structured with two main parts: Chapters 2 + 3 on ‘review’ and, Chapters 4+5 on ‘innovation’.

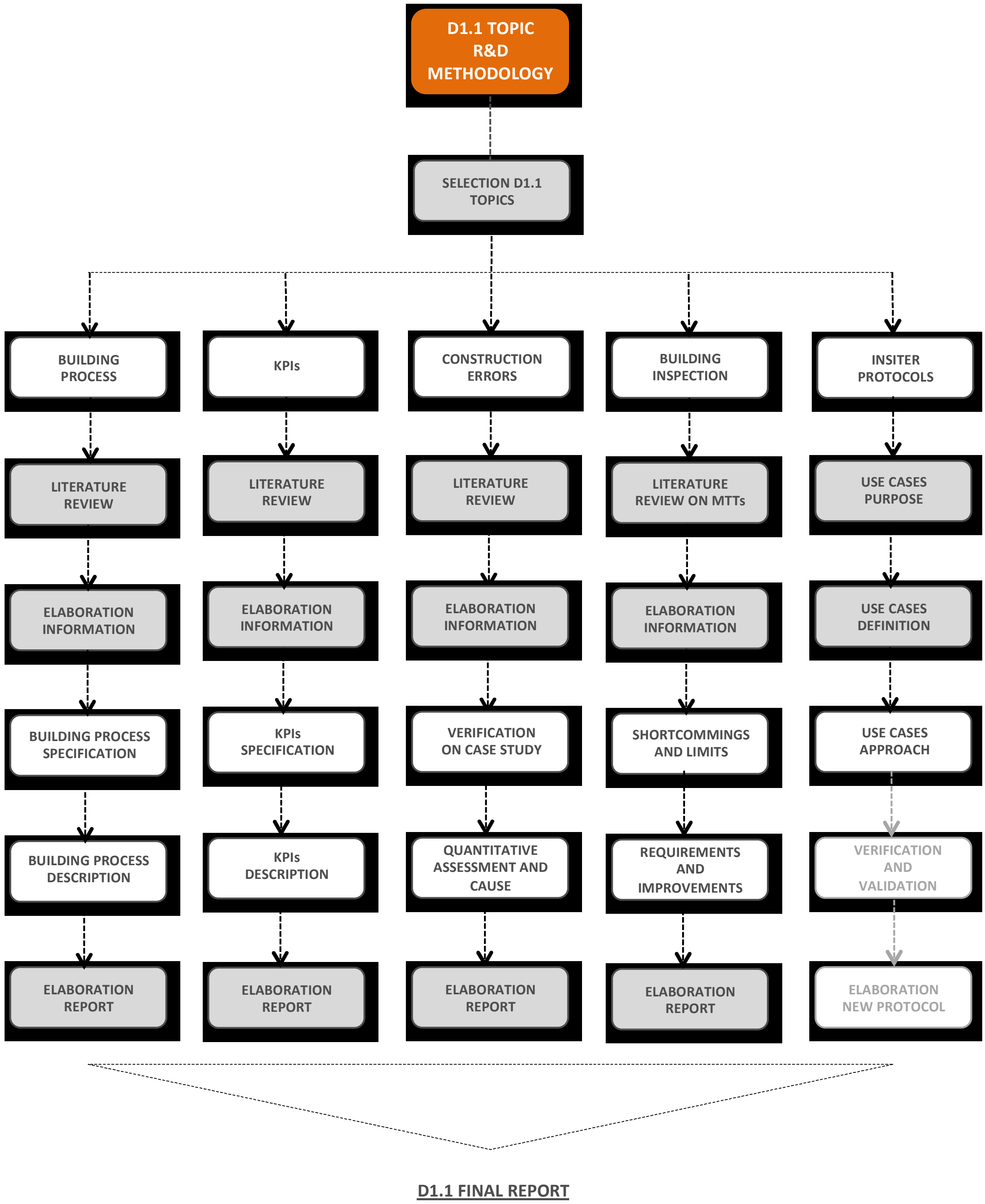


Fig. 3 – D1.1 R&D methodology

1.3 Main achievements and limitations

The deliverable presents the results achieved by T1.1 during the first year of the INSITER project that can be summarized in:

- Definition of a standard **building process** in order to improve the construction quality and energy performance of prefab buildings. In consideration of the INSITER focus, T1.1 has analysed the RIBA Plan of Work 2013 and integrated it with specific stages related to the manufacturing of building components (off-site) and the assembly of the building components (on-site);
  [See D1.1 – Chapter 2.1]

- Identification and presentation of **key persons** involved in the building process. Based on the main goals of INSITER, the harmonization of the role of each key person inside the process is an essential aspect connected to the building quality. At the same time the key persons could be considered as "stakeholders" of the INSITER results;
  [See D1.1 – Chapter 2.2]

- Selection of the main **EU technical norms** for building assessment and energy performance (direction of nZEB buildings). This task has been very important for the definition of the main EU standards used to evaluate the performance assessment and quality assurance during the process (in real-time also);
  [See D1.1 – Chapter 2.5 and Appendix 1-2]

- Presentation of the main **limits of existing inspection methods** used to measure the building quality and performance as well as to propose the **potential improvements** that INSITER could propose;
  [See D1.1 – Chapter 2]

- Introduction of **INSITER Key Performance Indicators** to measure the building performance and the project management. The deliverable also introduces the INSITER Effectiveness KPIs that will be applied in particular in WP5 to validate the INSITER tools.
  [See D1.1 – Chapter 4]

- Recognition of the main **architectural components and MEP-HVAC systems** for prefab energy efficiency buildings and description of the **most frequent construction errors** considering four categories of the building technological system: 1) envelopes; 2) interiors systems; 3) load bearing systems; 4) MEP-HVAC systems;
  [See D1.1 – Chapter 3.1]

- Elaboration of **innovative INSITER protocols** to prevent and to detect construction errors in consideration of: most frequent errors, WP1 KPIs and existing inspection methods;

The following table presents four limits suggested by T1.1 (Year 1 and D1.1) to define the scope of the INSITER project:

TOPIC	LIMIT
1. Building process	INSITER will analyse and apply the new methods only in the construction stages of the process in order to reduce the existing building gap between the design performances expected with the building constructed.
2. KPIs	WP1 will analyse the KPIs used to measure the building performance, WP5 will elaborate on the KPIs that measure the effectiveness of INSITER tools.
3. Construction errors	The construction errors presented in D1.1 only regard the technological systems in consideration of the energy performance and quality assurance.
4. Self-inspection procedure	The coming self-inspection procedure will be developed for the following types of buildings: 1) New construction of buildings with prefab components; 2) Refurbishment of existing buildings made of prefab elements; 3) Retrofitting of traditional buildings with the use of new prefab components. The procedures will be firstly developed without taking into account the type and use of the buildings (residential, commercial, industrial, public buildings etc.).

2. Critical review of performance assessment and quality assurance in the current practice

The chapter introduces the fundamental role of the design and construction process for the INSITER building quality presenting the current practice of building inspection, the existing shortcomings and potential improvements. It is also included the introduction of the relevant technical norms for building technical assessment.

It is important to consider the existing relations between the design and construction process.
In fact the building quality is result of different and complementary factors. The main factor is related to the application of a shared organisation and management design and construction process including all participants involved.
For this reason, it is essential to provide a common understanding of the "building process":

- Introducing the main tasks;
- Defining the main actors involved;
- Describing the outcomes of each task.

Regarding the model for the building design and construction process, the most important European guideline is the RIBA Plan of Work (PoW). The leading advantages of the RIBA PoW 2013 are represented by the fact that it is clear, simple, implementable, flexible and integrates sustainable design concepts. The negative aspects are that it is "design oriented" and does not consider in detail the construction and manufacturing building stages.

In consideration of the focus and goals of INSITER: reducing the main construction errors and times; maintaining the estimated construction-manufacturing costs; avoiding or at least minimizing the existing gap between the designed energy performance and the actual building behaviour; this chapter proposes a new model for the building design and construction process based on the original structure of RIBA PoW 2013.
The process proposed is organised in nine main tasks. The tasks consider the entire "building life cycle", excluding the demolition phase due to the fact that it is not relevant to INSITER.
Each task is described in detail introducing the main task objectives, actions and outcomes to achieve the expected results.

Please note that in the next research activities of WP1, the attention will be focused only on the "on-site construction process" (construction and manufacturing) in order to develop an innovative INSITER methodology for the building inspection.
This process is formed by protocols and guidelines for self-inspection and self-instruction (new, maintained and refurbished buildings) intended to be useful for the fields of general contractors and subcontracts, site supervisors, technical experts, quality auditors, clients and building occupants.

Anticipating these goals, the chapter provides a first glance at the key persons involved in the construction process, defining their main roles inside the process.

The critical review of performance assessment and quality assurance in the current practice of the building process is also presented introducing a practical example of the Dragados' factory.

The overview is completed with the introduction of the new trend and / or potential improvements proposed by new technologies and tools for building inspection and quality assurance.
The presentation of the adavantagies proposed by BIM and Augmented Reality is essential for the scope of the INSITER project.
In fact, in the last years the introduction of BIM has proposed a significant influence on the building process and in particular, on the construction of prefabricated buildings. BIM is a visualisation tool that enhances communication between architectural, engineering and construction industries (AEC). The concept is to virtually build a project, prior to building it physically, in order to work out problems and simulate and analyse potential impacts.
Various studies conducted prove that BIM is extremely helpful in reducing project costs, site conflicts, project duration, error reduction, as well as being more time efficient in the design development. Moreover, BIM has improved project communication quality among all actors involved in the process.
BIM proposes a new quality management plan of the construction. The quality control process begins with quality management plans based on the design drawings and specifications, which establish the quality of the material and equipment, the accepted criteria for the work in place and the inspection and testing to be performed.

The project manager, construction and production workers monitor all work and identify deficiencies (errors) beyond tolerable limits. Upon completion of the work, inspection and validation testing is conducted to verify compliance with the requirements of the approved construction documents. In general, the control of quality in a construction project consists of field inspections that guarantee that workmanship, physical properties, equipment and material supplied by the contractor are in line with the final design and specifications.
The INSITER BIM will be necessary to implement the AR that will help the construction workers to detect and to prevent the construction errors directly on-site. For this reason the chapter presents a general overview on the potential use of the AR in the building sector.

The construction errors detection and evaluation is strongly related to the EU norms, directives and standards on EeB and technical assessment presented in this chapter. The collection of standards and norms proposed show that there is a lack of harmonisation in Europe on technical norms for building assessement. Some directives and regulations, regarding main tracks and objectives, are defined, as well as norms that define quality of products. On the other hand, reference standards regarding the procedures and, in general, the construction processes, are still missing. The collected regulations/standards will form the starting point to create a common basis for the development of INSITER procedures. The focus of our research will consist in the definition of procedures to identify and quantify the construction defects. Therefore the identification of KPIs and related parameters is crucial: the existing norms and standards can help in this task, as well as in the definition of benchmarks. Given wide range of aspects that characterizes the building systems, the focus will be mainly centred on the prefabricated elements both in new construction and in renovation projects for existing building, with the aim at reducing errors and defects in terms of energy saving.

2.1 Brief description of building lifecycle stages of prefab buildings

The following paragraphs introduce the nine designs and construction stages *(Fig. 5)* and the key actors involved in the building process.

Analyzing the building process it is important to consider that the early design phases play crucial role for the future performance of a building. Bogenstatter points out, that early design stages determine up to 80% of building operational costs, as well as of environmental impacts. In the latter planning phases the change-possibility rapidly decreases with simultaneously increasing costs *[Bogenstastter U., Prediction and optimization of life-cycle costs in early design. Build Res Information 2000; 28 (5e6):376e86].*

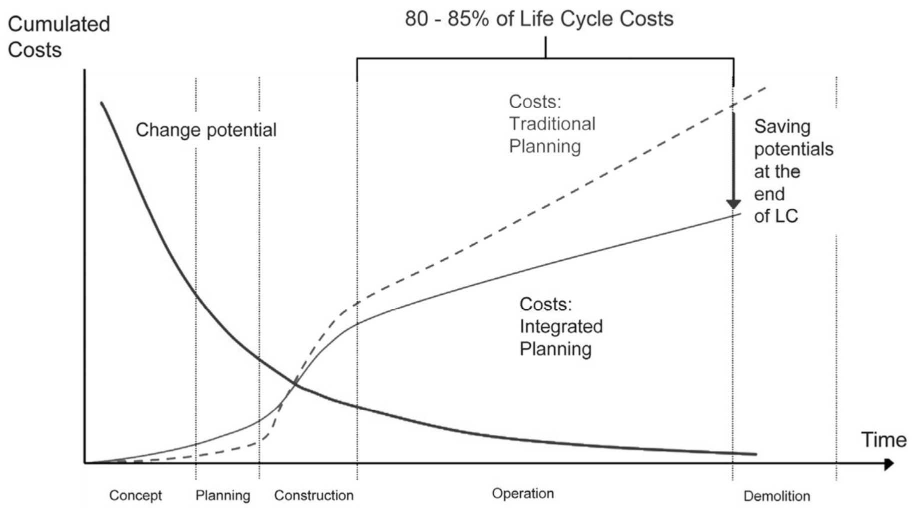


Fig. 4 – [Jones Lang LaSalle. Green Building e Nachhaltigkeit und Bestanderhalt in der Immobilienwirtschaft. 2008]. □ [I. Kovacic, V. Zoller / Energy 92 (2015) 409e419]

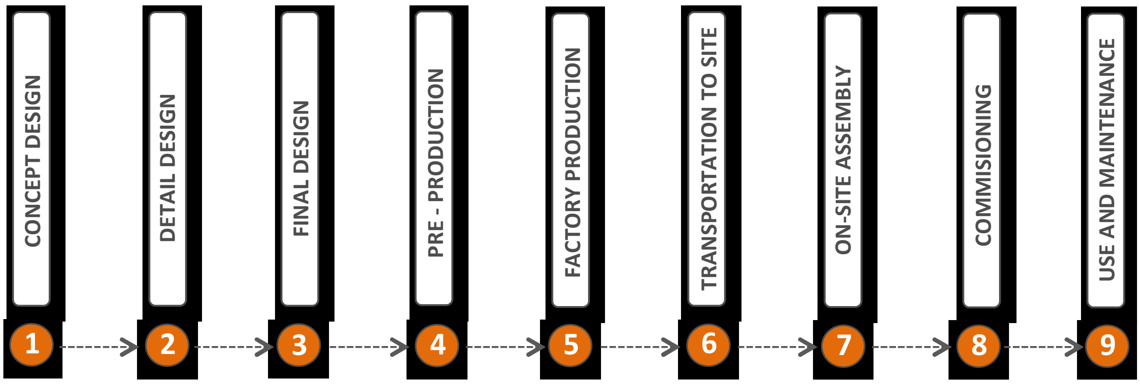


Fig. 5 – INSITER Prefab Building Process

2.1.1 Concept design task

Based on: 1) the definition of the client's needs 2) the scope of the project and 3) the initial project brief; the concept design task develops the project program and strategies.

To improve the energy efficiency of the building it is important to define, since this first task, the Sustainability Strategy and Aspiration (site, environmental requirements, existing facilities, building components, materials, MEP-HVAC systems, climate parameters). The facility and client requirements as well as the energy requirements will be implemented in this task. The selection of the main Key Performance Indicators that will measure the building quality and energy performance is part of this task.

In parallel with design activity, a number of other related tasks need to be progressed in response to the emerging design, including a review of the cost information, the development of a Construction Strategy, a Maintenance and Operational Strategy and a Health and Safety Strategy and updating of the Project Execution Plan.

The quality management of the process starts: establishing the project team and lead designer, defining the Technology and Communication Strategies and considering common standards to be used by all actors involved in the process.

As BIM gains further prevalence within the design and construction industries, building owners are now requesting only those firms that are BIM-capable as there are numerous advantages to BIM based projects. By having the capability to model current conditions, whether it is an existing building or the surrounding context, designers can grasp a better understanding of the site needs and directly from the conception of the project are able to better predict the impact of the design. As the model contains the necessary level of detail, routine analyses can be preformed and direct feedback can be obtained in regard to various design alternatives, resulting in more informed design decisions. BIM software enables virtual mockups to be made and tested at a fraction of the cost of physical construction; this visualisation also aids in the communication with the client, making it so that cause and effect are more easily understood and design decisions more quickly achieved. Having this strong foundation of understanding from the start ultimately allows for savings in all realms.

2.1.2 Detail design task

During this stage, the Concept Design is approved and is further developed. The design work is progressed until the spatial coordination exercises, as well as the building layout, have been completed.

By the end of this task, the architectural, building services, structural engineering designs as well as the MEP-HVAC designs will be developed following the project program. The lead designer will check all documents elaborated and the cost information aligned to the project budget.

The project strategies, including the energy performance of the building, will be developed further and in sufficient detail to allow the client to validate them once the lead designer has checked each strategy and verified that the cost information incorporates adequate allowances (Project goal in relation to INSITER: Energy efficiency, Building quality, Management quality). Other important tasks are: to obtain the authorization of local administration office and/or any other third party in relation of building regulations; review and update sustainability, Maintenance and Operational and handover strategies; review Construction Strategy, including sequencing, and update Health and Safety Strategy.

Review or update of the Project Execution Plan, including change control procedures, should be implemented to ensure that any changes to the Concept Design are properly considered.

As a project reaches the detail design stage, more trades become actively involved and critical decisions are made that can directly and indirectly affect the success of a project. Given the large amount of information that is being accumulated from the various contributors it is essential that collaboration is managed effectively. BIM software supports this cooperation through the sharing of up to date information and problem solving such as clash detection. Discovering and resolving collisions during the design phase spares money and time on the site. As greater preparation is now being completed during the design phase of a project, BIM is optimising the opportunity for prefabrication ultimately, giving way to a more factory like approach, cutting down on construction time and chances of error. In addition to prefabrication, BIM allows for building product manufacturers to create BIM objects of their goods that are linked to specifics such as financial cost, environmental cost, expected lifespan, customer service and availability. These cataloguing yields results concerning efficiency and the influence certain products are having on the overall performance of the building while also providing real time cost estimation. This lean process facilitates the discovery of inaccuracy at a time when it is still inexpensive and easily corrected while also making it possible to envision the influence of product and design variations

2.1.3 Final design task

Using the design coordinated during the previous stage, the designers should now be able to develop their Final Design (technical design) independently, with a degree of autonomy. Once the work of the design team has been progressed to the appropriate level of detail, as defined in the project program, eventually specialist subcontractors and/or suppliers undertaking design work will be able to progress their design work. The lead designer and other designers, where required as part of their Schedule of Services, may have duties to review this design information and to ensure that specialist subcontractor design work is integrated with the coordinated design. Support tasks are: review and update the Sustainability, Maintenance and Operational and handover strategies; review and update the Project Execution Plan; review Construction Strategy, including sequencing, and update Health and Safety Strategy.

The architectural, building services, structural engineering designs as well as the MEP-HVAC designs are now further refined to provide technical definition.

The use of BIM during the Final Design phase in a project is intended to aid in the reduction of conflicts, cost modeling and construction sequencing. It allows for a tighter coordination during design that ultimately carries into the realisation of the project. BIM software allows for extensive amounts of information to be stored in one place; this becomes a significant asset as the model becomes more complex. As various aspects are finalised, BIM automatically generates any updates or changes throughout all drawings, saving architects considerable amounts of time. This also enables more fluidity between tasks and supports the communication between disciplines. Another output from the BIM model is schedule sequencing. Charts can be extracted illustrating the dependency of tasks while also allowing for the investigation of changes and whether or not they affect the critical path as well as their impact on the delivery of the project. Once a project is completed it can be saved and stored as a case study for future projects to use as reference.

2.1.4 Pre-production task

During this stage, the building design is completed and all components have already been established and drawn, but the project is not yet constructible. The engineering of the project (pre-production task) is the stage in which all the prefabricated components are studied and are constructible combining the final design requirements with the technical knowledge of the construction industry. The pre-production phase of the prefabricated components is crucial to have correspondence between the requirements of the final design with the building construction.

To reduce the margin of error and to save time in the later stages of the construction process, it is necessary to design and realize the components imagining exactly how the components will be put on place on site and which are the technical characteristics of the components. Then, they can be assembled properly using technologies of an industrialised building site. The BIM can facilitate the pre-production phase. In fact, during the previous stages, all the key actors involved have established the preliminary technical characteristics of the components, including detection of potential clashes. The other advantage of BIM regards the possibility to verify the correctness of the components before they were transported to the construction site, by assembling the different elements of the prefabricated building virtually. The BIM-based technologies allow projects to be built faster, with fewer surprises and with lower costs. BIM also supports efficient and effective planning and coordination on the construction site. The model can include information such as locations of lorries, cranes, lifts and other large items as part of the logistics plan. This in turn accompanies a greater monitoring of health and safety precautions on site as the project progresses.

The key persons involved during this task are: project manager, principal/owner and construction workers. These key persons have the task to control and manage the whole production process to avoid errors and to save considerable amounts of time.

2.1.5 Factory production task

The factory production phase (off-site) is crucial to have a correspondence between the building quality established in the previous stages and the final quality of the building. In this stage it is important to reduce the uncertainty of the factory production to obtain components that have the characteristics established in the previous design tasks. Moreover the factory production of the components, in comparison of tradiational construction systems (totally on-site), provides controlled conditions for bad weather and for ensuring quality; it facilitates the compression of project schedule by changing workflow sequencing, reduces the waste of materials. In addition, it reduces on site, noise and dust disturbance and ensures the health and safety of workers *[Hong et al., 2015]*. Mistakes made during the components production become apparent during the following phase of assembly on site, resulting in a lengthening of the construction time and the consequent increase of costs. The BIM technology supports in verifying the correctness of the production of items in a virtual way, and it helps to identify eventual lack of correspondence between the various components in the assembly phase. The key persons involved in this task are construction workers/installers and production/manufacturing workers. They have the responsibility to monitor the various stages of production and on time delivery of prefabricated components.

2.1.6 Transportation on site task

The transportation of prefabricated components to the site is important in terms of work time reduction. The components must be delivered just in time to ensure a smooth workflow and to avoid the overlap and interference between the various stages of assembly. The higher the degree of prefabrication, the greater the influences of logistics on the construction programme. Logistics is the tool for saving time and costs on site. The shorter construction time and lesser need for temporary storage spaces, the higher the cost reductions are, especially for sites where site plant and facilities account for a high proportion of the total construction costs and on inner city sites *[Knaak, 2012]*. During the transportation task the key persons involved are the construction workers/installers and production/manufacturing workers. They are responsible of the correct delivery on site of the component and the correct storage of the components.

2.1.7 On-site assembly phase

During this stage, the building is assembled “on-site” in accordance with the Construction Programme. In this phase the prefab components (buildings components and MEP-HVAC systems) that have been fabricated “off-site” are put together. On-site construction works are crucial to maintain the expected building quality.

The procurement strategy and/or the designer’s specific Schedule of Services will have set out the designer’s duties to respond to design queries from site generated in relation to the design, to carry out site inspections and to produce quality reports.

Important output of this stage is the ‘as-built’ information. In this task it is important to check the quality of the works in relation of the project plan and expected requirements. The administration of the building contract will do regular site inspections and reviews the work progress. The sustainability strategies will be evaluated and the handover strategy will be implemented, including the agreement on the information required for commissioning, training, handover, asset management, future monitoring and maintenance and on-going compilation of ‘as-built’ information.

The project team will facilitate the successful handover of the building in line with the project programme and will conclude all aspects of the building contract, including the production of required certification.

BIM becomes an immense advantage when it comes to construction by eliminating many of the inefficiencies that often occur. It allows for the building to be built virtually, resulting essentially in a trial construction prior to the real construction. As there is one dynamic model, collaboration amongst the various contractors on the site is executed with more effectiveness and as prevention of possible errors was conducted during the design phases of the project, assembly of the assorted systems is more productive. The BIM model is continuously used on site for anticipation of potential inadequacies and helps with troubleshooting in the field. Ultimately, the necessary preventative measures are taken and with the ease of assembly aided by BIM, the entire construction process becomes more harmonised.

2.1.8 Commissioning task

The commissioning stage ensures and confirms the building performance / quality in comparison to the expected requirements. The commissioning process is the process for achieving, validating and documenting that the performance of the total building and its systems meet the design intent and requirements of the owner. When a building is initially commissioned it undergoes an intensive quality assurance process that begins during design and continues through construction, occupancy, and operations. The primary goal of commissioning any project is to ensure that success for the project is clearly defined in the final design task and that the building performs as intended to fulfill that mission. Today the main building inspections actions are concentrated in this task and completed when the bulding is in-use Post Occupancy Evaluation (POE). Particularly commissioning is referred to the process by which subsystems for mechanical, plumbing, electrical, fire/life safety, building envelopes, interior systems, co-generation, utility plants, sustainable systems, lighting, wastewater, controls and building security of a building were tested and balanced according to established standards prior to acceptance by the building owner. During commissioning there are different key persons involved in the process. The principal key persons involved are: principal/owner; project manager team; producer, and the commissioning team. Each group of professionals is responsible for the processing of his competence respect of execution of work.

2.1.9 In use and maintenance task

The building is constructed and will be handed over to the final user. The final user will be educated concerning the correct use of the building. This action is very important for nZEB's (nearly Zero-Energy Buildings) including the installation of high technology systems (MEP-HVAC) that improve the energy performance and reduce energy consumption.

During this task the handover strategy will be completed including: the completiotion of POE, the review of the project performance and the project outcomes. The project team will receive a feedback use by the end user during the future life of the building. The administration of the building contract is closed.

As a project is developed, the long term impact and function of a building can be more easily predicted with the inclusion of BIM. User experience is scientific, and in most instances, the end users' actions and impacts on the efficiency of a building can be predicted. By simulating this stage of the building life cycle early on in the project design, many concerns emerging from this period of a project are dealt with and resolved at a lower cost and in a timelier manner. BIM relieves much of the unpredictability that stems from the time when a building is in use; through representing 3D aspects of a building and the analysis of varying alternatives, BIM can help to reduce environmental impacts and operating costs resulting in a better functioning building that saves on time and money in the long run.

To maintain the original building qualities and performances it is necessary to propose periodical maintenance interventions based on the Maintenance and Operational Strategy. With intuitive self-inspection techniques the building quality will be analysed to define the necessary interventions on the: building envelope system, load-bearing system; interior system; mechanical and electrical system; plumbing system; HVAC system. This task proposes: preventative maintenance on building and facilities as well as regular inspections (on building components and on MEP-HVAC systems) using automated systems that monitor the building in real time.

With the incorporation of BIM, maintenance of a building becomes streamlined and more easily sustained. BIM models can either be created for existing buildings, or they can originate from the conception of a project, either way, actual particulars of a building are modelled and referenced throughout the life cycle of the building. As a building changes ownership, history of the project can be understood at a higher level and decision-making often becomes more factual. Given that the model can contain product specific information from manufacturers, preservation of these elements is traceable and beneficial. This can also generate a higher return of investment, as life expectancy and replacement costs can be foreseen and compared during the design phases of a project, enabling owners to evaluate investments and understand the possible benefits of larger investments initially, but an enhanced payback over the course of a building's life cycle.

2.2 Stakeholder analysis (key persons)

A number of the key persons characterize the building process. This section defines these roles in a more strict view of the "INSITER construction process", meaning from the perspective of prefabrication, together with the aim of self-inspection during the construction process in order to achieve the expected building quality and energy performance.
We speak of key persons as a profession. But depending on the process the key persons can work in the service of principals, advisers, contractors, manufacturer / suppliers, insurance companies, or governmental organizations.
Generally, we can discern the following main persons that characterize the building process:

- Principal / Owner: 1) Professional; 2) Non-professional;
- End-user: 1) With facility manager; 2) Without facility manager;
- Project manager;
- Advisers: 1) Architect; 2) BIM manager; 3) Structural Engineer; 4) MEP-HVAC Engineer / Building Physics; Engineer / Energy expert;
- Construction workers / Installers;
- Production workers.

All of these persons are treated and described on three different levels to better highlight and understand their (new) roles when prefabrication and self-inspection (sometimes in combination with self-instruction) are imposed on the traditional building process. These three levels are: (1) traditional building process, (2) prefabrication building process and (3) quality self-inspection.

2.2.1 Principal, Owner

Although we mention them as one, their roles can be very different, whether we talk about a professional principal / owner or a non-professional one. In general, the principal / owner (or his representative in the case of a non-professional principal) demands a certain quality (safety, durability, sustainability, indoor climate, energy-consumption, healthy environment, comfort, building physical parameters etc.) and requires proof of the quality. Traditionally, principals / owners are not actively involved in building process itself; apart from defining in more or less detail their demand(s) or question(s).

After being shown the (possible) solutions, they have a decision making role on which specific solution is going to be built. This decision making process is often stepwise, and usually facilitated by a client building adviser. After the selected solution has been built, partly or in total, the client again has the role of approving and accepting it. Again, usually helped by specialist advisers.

Prefabrication in principle does not change the core role of the principal / owner. It however offers a possibility of providing more insight in the end result earlier in the process and to get the 'final approvals' faster.

From the quality self-inspection point of view, both clients and end-users can be more directly involved in the building process, since especially the end-users can provide valuable feedback on the expected quality delivery. This is in a sense also true in traditional building process, but prefabrication could or even should provide a serious possibility of accommodating the end-user feedback more immediately – on just-in-time basis that fits well with the BIM design and manufacturing link potential.

2.2.2 End-users / Facility manager

The end-users are mostly not directly involved in the building process and in the quality control. Traditionally, the role of the facility manager is almost entirely focused on the 'in use' period of a building. There is however more need to involve facility managers earlier in the process, based on the Total Cost of Ownership (TCO) demands in the process. Furthermore, from the TCO perspective the role of facility manager changes also in his/her traditional role, since the decisions about operation and maintenance are increasingly looked upon from the TCO perspective.

Prefabrication theoretically makes life of facility managers easier, since better guarantees can be given on Life Cycle and Life Cycle Costing (LCC) of the building products and elements. In order to do so properly, facility managers need to timely provide their knowledge and expertise as input for the design phase, especially in cases of refurbishment and retrofit. Furthermore, they can be more explicitly involved in decision making on solution choices.

Quality self-inspection concerns foremost the as-designed and as-built check or comparison, in which facility managers should be able to be involved, because that should help them in own self-inspections during the operational and maintenance phases.

2.2.3 Project manager

The project manager has the knowledge on the system level and he knows all the performances of the components of the building and he can verify if the different design components respect the established requirements. Traditionally the central coordinating and steering role for the whole project is based on budget, planning, organization, communication and quality criteria.

Prefabrication implies improved organization, communication and coordination with the production manager, including logistics and possibly construction works. The quality criterion gains on importance, but at the same time prefabrication should make it easier for project manager to assess the quality during the project. Ideally, self-instruction and self-inspection by other involved persons only leaves information in a digital environment to the project manager.

During the manufacturing and construction processes the project manager can exchange information, data and indicators through self-inspection tools with other key persons and takes care of the performance on system level.

2.2.4 Advisers: Architect

In the traditional building process the architect is content-wise the central figure, and also the one that makes the translation and/or the link between the demands and overall solution. In this role, the architect tends to leave others involved in reactive mode; this certainly applies concerning quality definition, where architect is the adviser for the client.

Prefabrication offers the architect two main possibilities, plug-and-play solutions and purpose-fit one-off's. Depending on process management and construction quality, prefabrication offers just-in-time and unique solution perspectives.

Focusing on quality self-inspection, if fully applicable and 'compatible' in combination with skilled construction labour, the window of opportunity widens for architects. Their role is then to utilize the available skills, rather than to impose solution driven quality assurance procedures. However, in case skilled labour is not available, plug-and-play type of solution is the way to go, with essentially prescribed quality assurance with the producer / manufacturer. Self-instruction guidelines are then essential part of architectural design and manufacturing assignment.

2.2.5 Advisers: BIM manager

In traditional projects the BIM manager is non-existent, but in new building processes he is monodisciplinary involved in the more bigger and complex projects. Effective and efficient prefabrication and fully integrated design and manufacturing are not possible without good BIM management. The BIM manager as a separate person in this process is currently the most logical role in the new building processes. He partially takes over the role of the project manager, if properly facilitating 'all sides' involved around the BIM model.

From quality self-inspection perspective, the BIM manager is a key person in providing the self-inspection input and links, and taking care for a meaningful and effective feedback from use and construction phases to design and engineering – and even program of requirements definition.

2.2.6 Advisers: Structural engineer

Almost the 'most traditional' discipline, in ways of working, but also in ways of thinking: first problem definition; then solution development / structural design. Therefore usually reactive, something that is also cultivated in education, but also something based on which highly safe solution can be produced. Prefabrication offers parametrically the 'promised land' to the structural engineer. Combined with BIM modeling and detailed calculation possibilities, the main task for the "redefined" role of structural engineer is to think in variations instead of (almost automated) standardizations.

Quality self-inspection is generally highly guaranteed for structural engineering itself. The "Insiter building process" offers however others more insight in the effects of his/her decisions, and possibility for faster and/or more frequent iteration loops with the structural engineer. This applies almost entirely to the 'front-end' of design, until prefabrication. Self-inspection during construction is then almost self-evident and with a very limited role for the structural engineer, apart from random inspections and updates of self-instruction guidelines.

2.2.7 Adviser: MEP-HVAC Engineer / Building Physics Engineer / Energy expert

Traditionally we see that the three disciplines work one-dimensional in their own discipline. The disciplines are usually very late involved in the building process. This is with the higher demands for nZEB not possible anymore. Integrated solutions are essential to achieve the demands. For this reason we mention the three disciplines as one.

Depending on the level of prefabrication and complexity of the building, installation and building engineers play an important role in a robust design, production and mounting possibility of the prefabricated elements. The engineers should be a part of the design team of the manufacturer or even work for the manufacturer. Prefabrication makes it possible to more fully incorporate the advised solutions in the final product. Coupled with quality control and use of BIM, prefabrication offers the possibility to finalize the control phase before the start of construction process.

Integral quality self-inspection becomes crucial from the perspective of energy performance and is therefore key element of the INSITER building process.

2.2.8 Construction workers / Installers

Traditionally these actors are either very skilled and collaborative, or almost non-skilled and only specialized in one type of activity. They have no influence in most traditional development and design processes, but are making what is asked. Usually they are very flexible and improvisatory in their work, albeit based on own changing quality standards. In general construction workers and installers have very limited interest in, and limited total overview of the whole building “system”.

Prefabrication shifts essentially the craftsmanship to the factory. Construction itself becomes assembly work, often already under guidance from the manufacturer or even done by an assembly crew of the manufacturer. BIM modeling can provide detailed self-instruction guidelines.

The quality self-inspection makes these shifts even more evident, and probably also highly necessary. In cases of less standardized work and/or purpose-fit different building elements, skilled workers will probably need to get easy-to-use feedback links to design and production processes. At the same time, a construction team hands-on communication tool can help devise adjustable quality self-inspection procedures. The interface or connectedness between building and installation components is then the main quality issue. Self-instruction should cover ‘both worlds’ in order for effective focus on ’own’ self-inspections.

2.2.9 Production workers

Traditionally they are no key persons in building processes, since production of separate products has no big impact on the building process as a whole.

Prefabrication thus prominently introduces new key role in the building process. The manufacturer becomes responsible for the whole chain, from design, to production and finally to assembly of the prefabricated elements. Quality assurance is not only important for the element itself but also for its performance in the building. In the quality control system of the manufacturer the production worker plays an essential role. The BIM related skills, from the perspective of manufacturing, are essential in this transition to make the ‘as-build’ same as ‘as-designed’.

Quality self-inspection therefore has to take place in the factory, performed by production workers. They will also have a very important linking role between construction feedback loops to the development and design phases. Quality control also has to fulfil the demands of the liability insurance or guarantee systems.

2.2.10 Commissioning team

The commissioning team is intended to verify the compliance of the building to the needs expressed by the owner/principal during the design phase. The commissioning team has a primary objective of verifying proper installation, operation, and performance based on the project design. The commissioning of the facility, systems, and/or equipment provides verification, identifies issues and discrepancies, and if designed and constructed properly, ultimately enhances the facility total quality, control, performance, and efficiency, which in turn provides increased sustainability.

Normally, in a complex project, the commissioning team is involved from project initiation through one year of occupancy. In many cases and ideally, there is an ongoing building enhancing and commissioning program and team for the life of the building. The project development is a learning process where building performance decisions are refined to successive levels of detail over the course of a project's life cycle. At the beginning of the project the commissioning team makes a commissioning plan in which are established the key activities of the commissioning project. The principal activities are: establish goals for quality, efficiency and functionality of the project; establish commissioning scope and budget; establish testing and inspection plans, develop commissioning specifications; determine special testing needs. The commissioning team has to prepare commissioning documentation, which serves as the historical record of the "what, why and how to" of key delivery team decisions throughout the planning and delivery process. Commissioning documents the establishment of standards of performance for building systems, and verifies that designed and constructed work meets those standards.

2.2.11 Key stakeholders

Based on the above descriptions of (new) building process roles, the key persons regarding INSITER quality focus can be considered:

- **Manufacturer** that plays an important role from design, to production, to assembly of the elements on site and the guarantee systems. This means that a lot of traditional roles of advisers and builders/installers are now coordinated by the manufacturer or even work for the manufacturer. The role of the manufacturer changes from supplier (of elements) to co-maker or even to contractor. This influence the traditional roles in the building process in a great deal. Production workers and assembly workers determine the quality of the product and are responsible for the self-inspection.
- **BIM manager** as the hub of development and communication activities (multiple directions!), including translation of self-instruction guidelines to hand-on digital tools. The model should give a complete overview of all the quality checks on detail level and on the total building.
- **End-user** since the final perception of quality and therefore the final test is provided by them.

2.3 Current practice of building inspection

The chapter introduces the role of the building inspection and proposes a common inspection case study adopted by Dragados' factory.

The building quality is a criterion that influences customer satisfaction with regard to the performance of construction projects.

Inspection is one of the most essential processes in quality control. It is the act of measuring or carefully examining a product's quality and preventing defects to assure that the final product meets specifications and fulfills the customer's requirements. Moreover, effective quality inspection can avoid the very large costs and delays that are associated with re-doing the work.

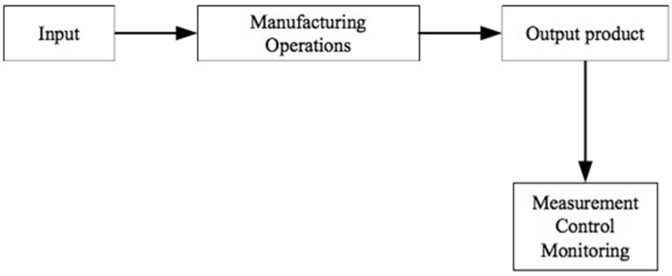


Fig.6 – Systematically presentation of production system.

Generally, quality inspection can be performed during the work-in-process and end-product stages. During the work-in-process stage, inspection is used to check work preparation for each work procedure to reduce the number of defects in the final product. Contrary, inspection during the end-product stage aims to detect defects or construction errors that must be remedied to improve the quality of the final construction product, including aesthetic issues in architectural work. Therefore, inspection during both stages is essential to control quality and to ensure that the quality of the end product meets the customer's requirements *[C. Laofor, V. Peansupap / Automation in Construction 24 (2012) 160–174 163].*

A finished product may exhibit several quality characteristics. Quality control (QC) techniques applied by inspecting and measuring the product quality characteristics use inspection equipment and inspection procedures.

For a single production system, the QC is applied into the output of the system as illustrated in *Fig. 7*. By comparing to the standard, it can be verified if the product meets the requirements.

Inspection provides useful information about the current demonstrated product quality. Then, any managerial decision made based on this information, which is concentrated more on the effort of product and process improvement program. Many procedures, especially for acceptance inspection, have been developed to conduct the inspection technically effective and/or economically efficient. Consistent monitoring on quality will ensure that products meet the requirements defined by either the manufacturer's product design department or by customers.

Inspections are performed at various times during the manufacturing process, including the inspection of raw materials and components from outside sources (incoming inspection), and final inspection of finished products to ensure the functional quality and the appearance of the product (outgoing inspection).

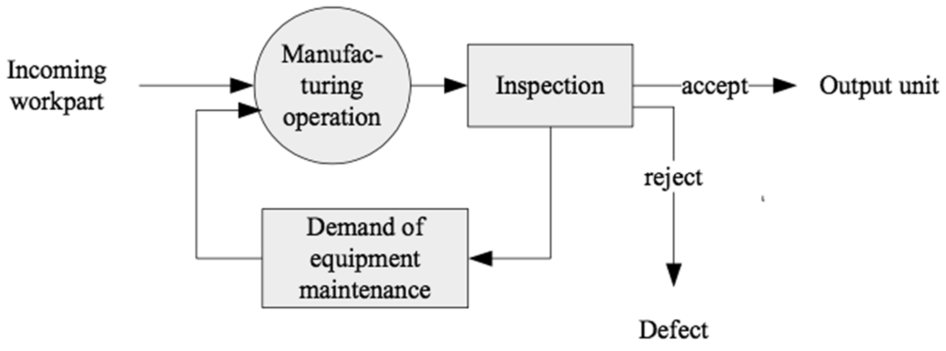


Fig. 7 - The framework of inspection and maintenance interaction in production system

The modern view of QC encompasses a broader scope of activities throughout a company. For instance, the total quality management philosophy suggested the process control inspection along production line rather than final inspection only. This diversion keeps the inspection as an essential technique in quality assurance and doesn't reduce the necessity for inspection instead. Industrial experience shows that although the manufacturer monitors its process at every stage, the acceptance inspection for incoming raw materials and inspection of the final product are still necessary.

2.3.1 Inspection case study: Dragados' Factory

As a reference for the current practices of self-inspection during each stage of the construction process, the process of INSITER partner Dragados has served as a case study. This chapter is strictly related to the innovative INSITER protocolos introduced in chapter 5 and to the construction errros presented in chapter 3.

Dragados's "Las Cabezas" Factory produces prefabricated Glass-Fibre reinforced Concrete (GRC) façade panels and complete 3D modules for prefabricated buildings in two separate production lines, both conceived and performed within Dragados ISO 9001 scope.

All manufacturing processes take place under the following regulations:

- UNE EN 14992:2007+A1:2011 Precast concrete products - Wall elements (It has a CE marking) → GRC Panels;
- European Assessment Document nº 593/12 → Prefab Modules;
- European Assessment Document nº 367R/13 → GRC Panels.

Design process quality control

Generally, the building's project design process (including drafting, detailed design and design control) is developed by external advisers. In these cases, Dragdos will support the design control within the advisers' specific procedure for that task. In case the architectural studio doesn't have an ISO 9001 with the design approach, the project will follow the Dragados GP-2.01 "Design control and development" which establishes the necessary actions in order to carry out the process, ensuring that the requirements specified by the client, as well as the legal and statutory requirements applicable, are met.

Off-site manufacturing process quality control

According to Dragados's GP-2.03 "Planning execution and control on site" the first thing to do when a new project arrives at the factory is to break it down into activities, which must then be analyzed, focussing on:

- Defining the most suitable construction method and execution period for each activity;
- Determining the most adequate sequence for the implementation of the works;
- Calculating the total time required for execution in order to ensure compliance with the contractual deadline. The duration of each activity and interconnection among activities are assessed.

The most common activities for prefab modules are:

- Casting
- Metal structure
- Module identification number
- Façade
- Roof
- Internal partitions and coverings
- Carpentry
- Floors
- Painting
- Electricity
- Plumbing
- Voice, data and other facilitie
- Logistics and transportation

Depending on the complexity of the Activity or the experience in implementing it, the Quality Manager will draft a **Construction Procedure** or **Method Statement** for it, and shall include it in the "List of Activities" where he will further indicate the preparation deadline for the aforementioned documents.

On-site assembly process quality control

Once the manufacturing is completed, the modules or the GRC are loaded into the trucks to the final location, the building site. There is a **Quality Management Plan on-site** controlling all the process before the handover, with the same structure at the Quality Control Plan of the factory, activities and material (in this case the material is our product) under control. As pointed out above, the project execution control is performed on planned activities and on the materials used in them. This control includes operations such as reception of materials, activity inspection and the execution of tests as specified in the planning. Control of the reception of materials (products) will be carried out following the points and frequency indicated in the **"Materials Reception Program".** To do so, the person in charge of receiving the material, signs the corresponding delivery note if all the provisions in the aforementioned program are met. When a material is rejected, the Quality Manager or the person in charge, arise a **Non Conformity Report** (SF-02 GP-4.01) to carry out appropriate actions to ensure that the problems found are solved. Execution **control for the activities** in "Las Cabezas" Factory, in accordance with the provisions in the Inspection and Testing Plan (ITP), are conducted on the elements of control (lots) provided in the planning. Such control will be included in SF-03 **"Activity inspection Status"**. This form lists the essential operations to be controlled for each activity and area, indicating also the subzones and lots making up the zone. When an operation is not accepted, a Non Conformity Report is generated.

The Quality manager, or the person in charge, will decide which actions have to be taken in order to solve the problem temporarily or to have better information on the decision to be made. The GP-4.01 **"Non-conformity management"** is the procedure that "Las Cabezas" Factory uses to establish the necessary actions in order to develop a process to detect, identify, manage, document and close the Non-conformities (N.C.) that may occur during the project execution.

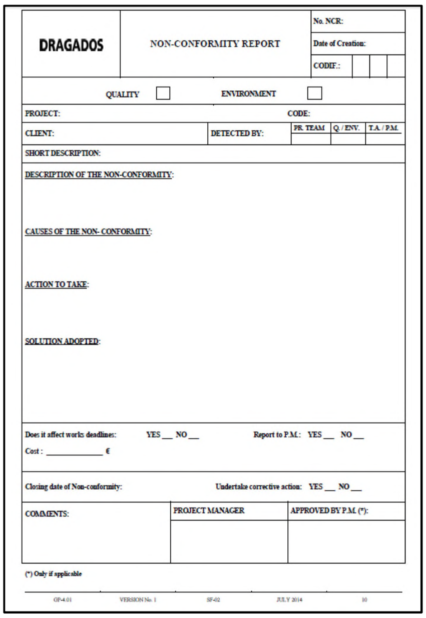

DRAGADOS
NON-CONFORMITY REPORT
No. NCR:
Date of Creation:
CODIF.:
QUALITY
ENVIRONMENT
PROJECT:
CODE:
CLIENT:
DETECTED BY:
PR. TEAM
Q. / ENV.
T.A. / P.M.
SHORT DESCRIPTION:
DESCRIPTION OF THE NON-CONFORMITY:
CAUSES OF THE NON- CONFORMITY:
ACTION TO TAKE:
SOLUTION ADOPTED:
Does it affect works deadlines: YES __ NO __
Report to P.M.: YES __ NO __
Cost : ____________ €
Closing date of Non-conformity:
Undertake corrective action: YES __ NO __
COMMENTS:
PROJECT MANAGER
APPROVED BY P.M. (*):
(*) Only if applicable
GP-4.01 VERSION No. 1 SF-02 JULY 2014 10

Fig. 8 - Standardised Form SF-02 GP-4.01

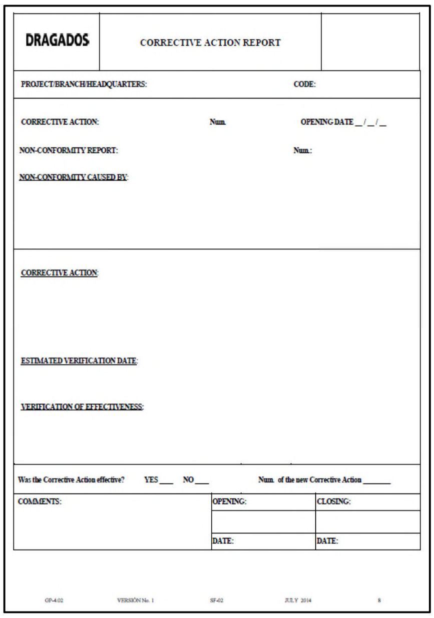

DRAGADOS
CORRECTIVE ACTION REPORT
PROJECT/BRANCH/HEADQUARTERS:
CODE:
CORRECTIVE ACTION:
Num.
OPENING DATE __ / __ / __
NON-CONFORMITY REPORT:
Num.:
NON-CONFORMITY CAUSED BY:
CORRECTIVE ACTION:
ESTIMATED VERIFICATION DATE:
VERIFICATION OF EFFECTIVENESS:
Was the Corrective Action effective? YES ___ NO ___
Num. of the new Corrective Action ______
COMMENTS:
OPENING:
CLOSING:
DATE:
DATE:
GP-4.02 VERSIÓN No. 1 SF-02 JULY 2014 8

Fig. 9 - Standardised Form SF-02 GP-4.01

Finally, the Quality manager will, in accordance with the Factory Director, decide whether it is necessary to undertake any Corrective Action (described in GP-4.02 **"Corrective and Preventive action"**) in order to eliminate the root causes of the non-conformity, so that its recurrence is prevented.

Some of the most important and recurrent shortcomings that have been detected while performing the quality control of the construction method of the prefabricated 3D modules are the **thermal bridges** produced in two specific areas of the modules. These two areas are the perimeter beams joints and the joints between the GRC with the module slabs.

Although these problems have not yet been solved, they have been identified and categorized, being their origin related to the "Incorrect assembly of building components" (One of the most common errors identified in this deliverable within the category "Common construction errors of the building envelope").

2.4 Shortcomings and potential improvements in the current practice

The industrialization process is the main characteristic of prefab building as present in the chapter 2.3 and 3.1 of this deliverables.

Prefabricated construction refers to the practice of producing construction components in a manufacturing factory, transporting complete or semi-complete components to construction sites, and finally assembling these components to construct buildings (see chapter 2.1 and 2.3).

Compared with conventional construction technologies, prefabrication provides controlled conditions for bad weather and for ensuring quality, facilitates the compression of project schedule by changing workflow sequencing, and reduces the waste of materials *[J. Hong et al. / Journal of Cleaner Production 112 (2016) 2198e2207].*

Despite this, the main inspection procedures to evaluate the building quality and energy performance are generally scheduled when the building is constructed or in-use.

In order to check the construction quality and to receive the occupant feedback, the traditional practice proposed is the Post Occupancy Evaluation (POE). This is a process of systematic evaluation the performance of buildings after they have been built and occupied for some time. The requirements of building occupants, including health, safety, security, functionality and efficiency, psychological comfort, aesthetic quality, and satisfaction are essence of these studies. According to *[Zimring & Reizenstein]*, POE is 'the examination of the effectiveness for the human users of occupied designed environments. Effectiveness includes the many ways that physical and organizational factors enhance achievement of personal and institutional goals'.

[Preiser] defined POE as a "diagnostic tool and system, which allows facility managers to identify and evaluate critical aspects of building performance systematically". According to *[Preiser]*, POE studies can be classified under three headings: 1) indicative, 2) investigative, and 3) diagnostic. The general properties of these POE types are:

1. Indicative POEs are based on quick walkthrough evaluations involving structured interviews with key personnel, group meetings with end users as well as inspections;
2. Investigative POEs utilize interviews and survey questionnaires, in addition to photographic/video recordings, and physical measurements, to add more depth to the analysis;
3. Diagnostic POEs can take months or years and require highly sophisticated data gathering and analysis techniques focused on a wide range of performance evaluation aspects.

[O. Goçer et al. / Building and Environment 89 (2015) 14-27].

Dragados has briefly presented a current example of inspection (limited to the building components) considering: 1) design process quality control; 2) off-site manufacturing quality control; 3) on-site assembly process quality control.

Through a literature review and analysis on the market, it is possible remarks several limits of the current "building inspection" methods not presented in the preview chapter:

- High level of subjectivity, which demand technical inspectors with individual experience to reduce the different perceptions without a uniform standard (e.g. the same person might even make different judgments on different days);
- High costs and time consuming;
- Difficulty to determine all construction faults, it is not possible for a person determine all possible defects;
- Lack of data storage and management systems, a person's ability to judge aesthetic faults are limited in that it cannot quantify the value of a given defect.

Futhermore, the existing inspection guidelines are insufficient or not fully useful for the purpose. The guidelines are general and apply to project types, product types, material types, or construction process types. Due to the generality of these guidelines, they leave the burden of identifying the inspection tasks that are important to a specific project to an inspector. Moreover, due to their generality, these guidelines cannot reflect specific inspection needs that a construction project might have. A construction project always has specifications tailored to its specific characteristics and features. These project-specific specifications state unique quality requirements, which should be checked during inspection, but they are not included in existing inspection guidelines *[F. Boukamp, B. Akinci / Automation in Construction 17 (2007) 90–106].*

The traditional field inspection process has three main stages: recording, correcting, and reporting. The quality of traditional safety reports generated through field inspections has been recognized as being inadequate mainly because of the inefficiency and ineffectiveness of the process *[N.-W. Chi et al. / Automation in Construction 64 (2016) 78–88].*

The actual shortcomings introduced denote that the construction sector (new building, refurbishment and maintenance) requires new standards to monitor in real time, in aeach task of the process, the performance assessment and building quality. It is very important to plan progressive technical checks since the early stages of the decision-making process to prevent and normalize the risk of construction errors. For this reason, it is necessary to promote the use, during the main tasks of the process, of smart technologies and tools able to communicate "quickly" and in "real time":

1. The building quality;
2. The presence of damage and/or
3. Performance not in line with the project objectives.

Effectively, the continuous monitoring in real-time (using for instance smart sensors) allows you to identify the construction problem or defect before it is visible, making more timely repairs, reducing the costs and above all increasing quality. Furthermore, integrating Virtual Model (realized using BIM software) and AR in the inspection process, it is possible visualize "intuitively" all data information collected regarding the technological systems analysed. For example, pointing our devices (tablet, smartphone or smart glasses) into a specific part of building we can immediately see any problems.

Because the use of AR integrated with BIM is a crucial part of INSITER, in the following part we propose a general presentation of the advangatges proposed by AR and BIM inside the building process and inspection. This information and suggestion will be usefull in particularly for WP2, WP3 and WP4 of INSITER project.

At the end of the chapter the main inspection tools proposed by INSITER are also introduced.

Augmented Reality advantages

The following parts introduce the AR advantages in order to reduce the construction errors and to improve the building quality considering the design, construction and in-use tasks as potential improved proposed by INSITER.

Part of the text is based on the contents proposed in *[R. Abboud, Architecture in an Age of Augmented Reality: Opportunities and Obstacles for Mobile AR in Design, Construction, and Post-Completion].*

AR is an advanced computer-based visualization technology in the research stage that has potential to provide significant advantages to the Architecture, Engineering, and Construction (AEC) industry. For at least a decade, several AEC researchers have promoted AR technology adoption because of its potential as a visualization aid. *[Roberts et al.]* developed an AR system to render images of underground structures onto a view of the site *[Hammad et al.]* and *[Thomas et al.]* found the potential benefits of AR in infrastructure field tasks and architectural assembly guidance, respectively. Some researchers demonstrated AR systems for planning or design process such as design detailing, outdoor architectural designs, and urban planning. *[Behzadan and Kamat]* proposed an AR system for AR rendering of construction processes onto the construction site.

However, most of them did not explicitly consider the characteristics of AEC work tasks such as inspection. Most of the researchers, however, did not focus on the accurate and precise registration of virtual images onto real images, which is critical for inspection tasks *[D. Shin, P.S. Dunston / Automation in Construction 19 (2010) 169–182].*

During the design tasks, as introduced in chapter 2, the architect develops a design to meet a client's needs, and visually communicates this to project members, from the client; to local authorities and specialist consultants; and increasingly, the public.

The architect produces spatial solutions to address the stakeholder requirements using a variety of media and presents these to the client for assessment and selection. In this field the BIM and AR can contribute: 1) to improve the comunication among the person involved in the process and 2) to reduce the trasmission erros (to prevent and self-instruction).

Defintely, AR integrated with BIM on a construction site will have a good impact on the communication of information between the architect and the contractor reducing the construction errors. Also, AR promises to impact the design process by bringing the designer more into direct contact with the building site. AR will influence future design review processes, by expanding the media from which designers draw to make design decisions. Mobile AR platforms may allow building designers to gain an immediate "reality check" of a building's surroundings early in the design process, and quickly contextualise their designs. Today's design visualisations typically freeze a building design within strategically selected "hero shots" that present the building to best effect. AR's real-time nature encourages designers to consider and evaluate their designs across a range of timeframes, and from multiple viewpoints.

AR use alone will not lead to 'more honest' design representations, as the viewing angle and virtual data overlay can all still be set by their users. Instead, use of AR will encourage the production of virtual designs that more closely respond to their real world context.

AR applications may communicate architectural narrative by overlaying information otherwise inaccessible to the viewer onto a building or architectural detail. Use of AR can bring an immediacy, interactivity, and playfulness to a narrative experience by drawing users into direct contact with a real site or artefact.

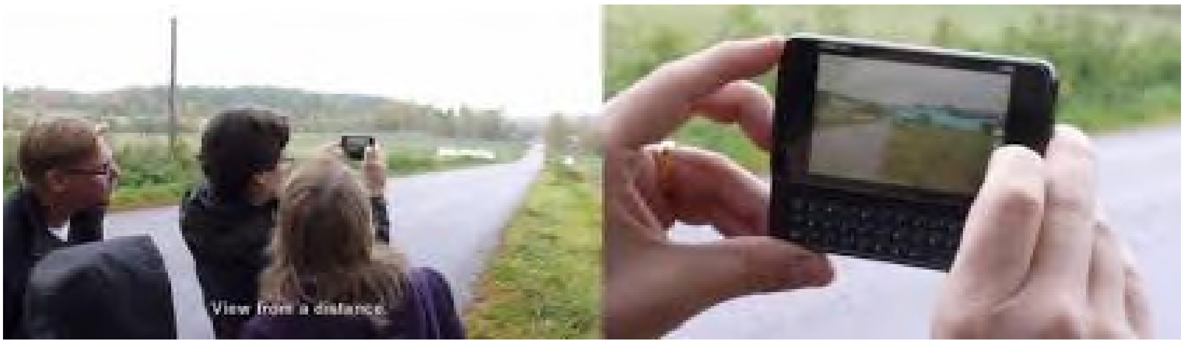


Fig. 10 - Raseborg & Jätkäsaari/Kämp Tower Tours - AR to present the plan directly on-site. This example proved that AR technology could be reliably used outdoors for full-scale design visualisation.

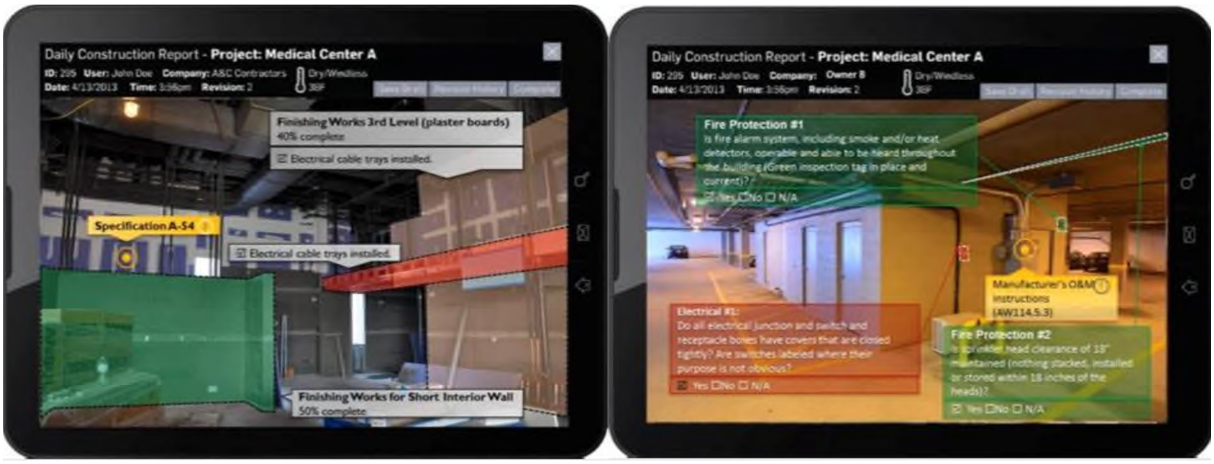


Fig. 11 - PAR Works' Mobile AR app, by researchers at the University of Illinois, allows users to geo-tag elements on a building site in real-time, and call up relevant specifications or information pertaining to any building component directly on site. The portable mobile display acts as an interactive 'Site Diary' for its users, and is accessible both on and off the project site. The app allows daily reporting and retrieval of information, online as well as offline.

In the construction process, AR can provide 3-dimensionally registered instructions onto physical components to provide task support for assembly processes. In fact, companies that employ AR for repetitive manufacturing processes do so to increase effectiveness (fewer errors), and efficiency (shorter time to complete the task) through the use of context-sensitive, up-to-date and media-rich information.

AR applications can display instructions to those assembling components using voice commands or visual display clues. AR apps that augment a worker's view can call up assembly instructions, specifications, and relevant standards to support construction processes. AR instructions may be seen from all viewpoints, allowing workers to concentrate on the assembly task without the need to interpret written manuals.
In consideration of INSITER, AR is ideally suited to prefabricated building construction.

AR visual and auditory overlays may assist users to carry out complex repair and maintenance tasks on building systems. By directly overlaying real-time computer graphics onto actual equipment, persons with little or no prior training may be guided through maintenance or repair tasks on complex machinery and equipment.
Mobile AR training apps enable off-site collaborators to monitor and assist in building component repairs, by providing live communication links to the user on-site. Integrating such a "real-world knowledge base" with detailed 3D models can allow mobile AR applications to train building operators independent of a user's geographic location. Buildings with highly specialised component parts and/or numerous modular elements are ideal candidates for mobile AR apps that aid in maintenance or repair tasks; this is especially true where the cost of developing a custom app is offset by savings in the on-going future training of building operators (relation with INSITER WP6 – Training).

BIM adavantages

Building Information Modelling (BIM) is one of the recent efforts that are aiming to increase data interoperability, information quality and collaboration between the project participants within a construction project. BIM can be defined as the information management process throughout the lifecycle of a building which mainly focuses on enabling and facilitating the integrated way of project flow and delivery, by the collaborative use of semantically rich 3D digital building models in all stages of the, project and building lifecycle *[Underwood and Isıkdag, 2011]*.
The use of BIM facilitates productive communication between architects, construction managers, mechanical engineers, electrical and plumbing engineers, subcontractors, and other project team members. It facilitates precise documentation, faster decision making, improved communication between parties, optimisation of resources, more efficient workflow, increased productivity, and decreased errors. Even after the construction phase, valuable information can be used by the facility operator for asset management, space planning and maintenance scheduling in order to improve the overall performance of the facility or a portfolio of facilities.
BIMs cover an extensive amount of information regarding the attributes of the building (elements) and the processes of the construction lifecycle.
They are accepted now as the sine-qua-non enablers of AEC data level interoperability and integration. Today BIMs, with their enhanced capabilities, have the advantage of integration with other information systems (Geographic Information Systems, Virtual Reality Simulations, etc.) or devices to acquire, store or share data *[Isikdag et al. 2008; Rüppel and Schatz 2011; Yanet al. 2010; Xie et al. 2011].* BIM data may be geo-located directly on the construction site using AR to communicate project information during construction. Overlaying BIM data onto what is actually in place may benefit professionals undertaking site inspections, and contractors checking construction progress. AR+BIM may confirm precise installation locations for construction components; locate materials, equipment and safety zones on a project site; and locate construction and project component details for more efficient communication of this data to site workers.

The design BIM-approach makes it possible to control the performance levels, the performance indicators and the specific characteristics of the different building components during the design process and instantly verifies the accordance between the project requirements and the components that can be used to design a specific building. The use of BIM also allows checking the possible interference between the different design phases and facilitates feedback-loops from the construction phase to the design phase. Through automatic devices of the BIM-software the designers may know which are the most critical aspects of the building design and quickly identify the specific problem related with a component or a part of the building.

Regarding the INSITER project, the relevant BIM benefits can be listed as follows:

- Better design;
- Reducing rework;
- Better collaboration and communication among all key actors of the process;
- Maintain the estimating costs;
- Improve the energy efficiency and sustainability;
- Synchronising design and construction planning;
- Clash detection;
- Reducing conflicts and changes;
- Verification, guidance and tracking of activities;
- Use of design as a basis for fabricated components;
- Better process to manage and operate buildings.

INSITER will promote the application of this technology in the new “self-inspection and self-instruction” process to facilitate the inspection and/or building manufacturing.

Tools for self-inspection

INSITER propose the integration of a set of hardware and tools available on the market to optimize and resolve the shortcomings.

This tool set will be necessary:

- To measure (with more detail in comparison to the traditional systems), the performance condition “on-site” based on the KPIs and measurements parameters;
- To reduce the human incidence and propose a progress automated inspection;
- To reduce the inspection time and, at the same time, to propose a continue monitoring;
- To identify a greater number of defects.

In the last years, different “diagnostic technologies” have been developed to support inspectors during quality control:

- “Thermal and infrared multispectral camera”: useful for energy auditing of building insulation, detection of air leakages, moisture detection, thermal performance, checks plumbing and piping;
- “Acoustic imaging systems”: innovative way to solve sound issues;
- “3D laser scanner”: main instruments to measure (with high level of precision) indoor spaces as well as building in three dimension;
- “Blower door test”: to help determine air tightness during energy audit;
- “Thermal sensor and humidity sensor”: to measure the indoor environmental quality;

To improve the current practice INSITER will test this equipment characterized by two main values: “portability” and “non-destructive testing”.

Several research efforts have attempted to improve the traditional field inspection workflow and to develop innovative tools that can be used on portable computing devices for digitalizing and automating the generation of inspection reports *[N.-W. Chi et al. / Automation in Construction 64 (2016) 78–88 87].*

INSITER follows this trend; where the potential improvement of the self-inspection proposed is based on computer/device vision and image-processing to detect construction errors and correct positions as well as quantify defect level. Moreover, the image-processing techniques can be integrated with tools for data collection and transformation such as digital camera, wireless sensors, etc. to automate the inspection process or monitoring.

For istance, over the past few years, thermographic inspection using thermal cameras has become prevalent for the detection of thermal defects and air leakages in existing buildings. Thermography is defined as the process of detecting and measuring heat variations emitted by an object under inspection and transforming identified changes into visible imagery. In the context of building energy performance modeling, thermography can be a robust tool in recording, analyzing and reporting actual energy performance of the buildings. Thermal images captured from buildings are directly influenced by energy performance deviations caused by insulation voids or thermal bridges (construction problems related to construction errors).

Again, reality capture technologies, like “3D laser scanners” and “embedded-sensors”, have started to be utilized on construction sites. These technologies enable more accurate and comprehensive monitoring of existing site conditions and produce large quantities of digital data describing the as-built conditions at the time of data collection. To perform quality control, this digital data has to be compared to a given design and to quality requirements of a project, which are derived from construction specifications. Using such a system, it is possible to overlay 3D as-built information, captured using laser scanners, with a 3D design model to identify and highlight geometric deviations.

In conclusion of this chapter we have summarized in Fig. 12 the main 5 shortcomings and potential improvements of the building inspection.

It is possible remarks that the main interesting subject of the INSITER innovation will be the general contractor and sub-contractors that can see the construction quality during the manufacturing but also in the entire building lifecycle. Other important categories are: site supervisor, technical expert, clients and building occupants. Nevertheless, indirect stakeholders may also be insurance companies.

INSITER promotes a new concept of self-inspection, which is very different to the current practice and can be summarized: “prevention is better than repair”.

Main shortcomings	Main potential improvements
• The inspection procedures are scheduled when the building is constructed or in use (See POE).	• To use smart technologies able to inspect “quickly” and in “real time” during all process stages.
• The manual-visual inspection is characterized by a high level of subjectivity, high costs and time consuming.	• To reduce the subjectivity level, costs and time of the inspection proposing the use innovative tools available on the market.
• The manual-visual inspection does not detect all construction errors.	• To integrate Virtual Model and Augmented Reality technologies in the inspection process.
• The actual inspections denote lack of data storage and management systems.	• To detect construction errors using computer/device vision and image-processing.
• The existing inspection guidelines are insufficient or not fully useful for the purpose.	• To elaborate new self-inspection guidelines able to use during the construction process.

Fig. 12 The table introduces the main 5 shortcoming and potential improvements to improve the building inspection.

2.5 Relevant technical norms for building technical assessment

This chapter presents an overview of available standards and guidelines dealing with condition assessment and quality inspection norms.

Condition assessment originates from the residential sector in the UK and the very first attempts were conducted by the Housing Condition Surveys to determine the quality of dwellings both from the structural as well as the mechanical perspective (MEP/HVAC). Condition assessment has changed maintenance approach from a corrective to a preventive one.

During the last two decades, the construction industry became more and more aware of the importance of timely detection of construction defects and taking corrective measurements. From that perspective, Building Commissioning has been developed as a process in which a building, under construction, undergoes an intensive quality assurance that begins during design and continues through construction, occupancy and operations. Commissioning ensures that the new building operates initially as the owner intended and that building staff are prepared to operate and maintain its systems and equipment. However, Building Commissioning processes suffer from subjective perceptions of inspectors and the availability of all inspection knowledge from different building disciplines.

On the other hand, inspection procedures are also beneficial for existing buildings, in the phase of analysis and assessment of the actual condition of a building, or of a part of it, and the evaluation process in defining the actions to be takes (retrofitting, replacement, major renovation).

INSITER will develop procedures to benefit construction workers in dealing with the inspection processes and timely detecting of construction defects. The new self-inspection process will be adapted to the whole construction process. For this purpose, existing condition assessment and inspection norms need to be inventoried.
Due to the large number of norms, condition assessment will be discussed in general; only relevant norms will be listed. Some inspection processes require using inspection instruments; in that case those instruments will be listed as well.

The collected standards will serve as an input and reference for the INSITER guidelines (D1.2 and D1.3 at M36) that are to be developed throughout the project and will be presented in the upcoming deliverables of WP1 of the INSITER project. The collection of the standards was a joint effort of the project partners, however, only the standards from the main contributing countries were selected, that being the Netherlands, Italy, Spain and Germany.
As introduced, the section presents a list of standards, that based on their title are relevant to the INSITER project. A subdivision was made between:

- Condition assessment and inspection norms and methods for “building components”
- Condition assessment and inspection norms for “MEP-HVAC components”.

From the list a selection was made of standards that appear to be most relevant to the INSITER objectives. In one-way or another, they can be related to self-inspection during the assembly phase of prefabricated building components. These norms were analyzed in more detail and their main contents shortly described, followed by a wrap up of important aspects to be taken up in the INSITER guidelines.
In Appendix 1 and 2 the whole list of standards relevant to INSITER is taken up.

2.5.1 Standard for condition assessments

In the Netherlands, the “*NEN 2767 Condition assessment”* for building and MEP/HVAC aims at objectively assessing technical quality of building. The standard includes: *1) NEN-2767-1 Methodology; 2) NEN-2767-2 List of faults and 3) NEN-2767- 2 Infrastructure.*

The NEN-2767 standard is applicable to:

- Visualization of the physical condition;
- Maintenance planning;
- Prioritizing of maintenance budgets;
- Control of physical conditions;
- Communication about the actual assessed physical condition and desirable condition.

In Italy, the "*UNI 10721 - Technical control surveyor service for buildings and civil engineering"* works aims at objectively assessing technical quality of building. The standard includes *"UNI 10722 – Building - Qualification and control of building project and design for new constructions - Part 1: Principles, General criteria and terminology, Part 2: Design planning of a single work and Part 3: Planning of design and planning and carrying out of design control in buildings works".*

The UNI 10721 standard is applicable to:

- Mechanical resistance and stability;
- Safety in case of fire;
- Hygiene, health and environment;
- Safety and accessibility in use;
- Protection against noise;
- Energy saving and heat retention;
- Sustainable use of natural resources;
- Durability, maintainability and useful life

2.5.2 The condition assessment process

In this section the process of NEN-2767 will be described in order to understand what the condition assessment process looks like and how it has to be implemented in the whole building process. Other tasks of WP1 will deal with how to integrate all relevant condition assessment and norms in the new methodology (Fig. 13). In general, the assessment condition process is as follows *[Straub, 2009]:* The inspector decides on the defect (type), its importance (Critical, Serious or Minor), its Intensity (Intensity 1 Low, Intensity 2 Middle or Intensity 3 High) and its Extent class (from class 1 to class 5). Based on these data, the inspector determines the condition rating.

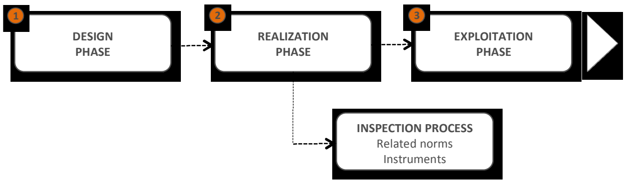


Fig. 13 – Insiter focus is related to the building inspection "on-site" during the building construction. The norms and standard are very important to compare the building performance with quality standard and to define if the defect level is acceptable or not acceptable.

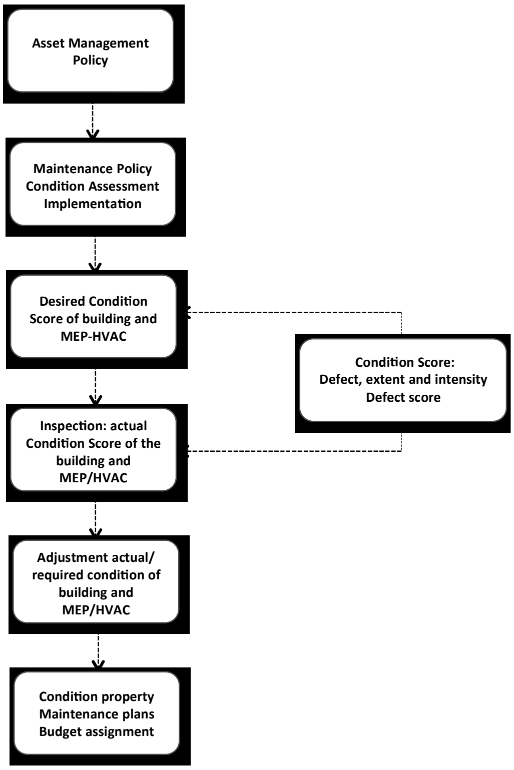


Fig. 14 – General assessment condition process

2.5.3 Condition assessment and inspection standards for building components

NEN 2767-1:2011/C1:2013 NL - Condition assessment - Part 1: Methodology and Part 2: Lists of faults

This standard describes a method to establish the technical quality of building and installation components univocally. The methodology states that the building condition does not influence business. Important parts of this method are the lists of faults. These lists are applicable to constructional and building related installation technical elements inclusive sites and site facilities belonging to the building.

Relevant aspects for INSITER:

- The building is logically subdivided in components;
- Classification of the importance of the defects (To what extent does the defect influence the functioning of the building component?);
- Classification system for severity of defects in condition (What is the state of degradation of the defect?);
- Guidelines on determining the extent of the defects;
- Condition ratings, one score based on the importance, severity and extent of the defects;
- Visual inspections, with use of measuring tools and other equipment at small scale;
- Inspections carried out by trained inspectors.

NEN 3682:1990 NL - Dimensional control in the building field - General rules and guidance

This standard sets generic rules for dimensional control of building elements, for the positioning on-site of building elements, spaces and joints regarding residential and non-residential buildings.

Relevant aspects for INSITER:

- Instructions on the positioning of measurement points;
- Instructions on the registration of measurements;
- Instructions on the operation of tools;
- Definitions of deviations.

UNE 85247-11 Windows and doors. Watertightness. Site test

This norm defines the method to use in order to identify water penetration points in windows and doors once installed in a building. It helps to identify the correct installation of a window or door through the verification of the absence of water penetration during the established time.

Process to follow:

- Visual inspection of the installed element (sealing, insulation and anchoring);
- Opening and closing of ventilation devices and panes, actioning blinds and all protection elements;
- Sprinkling water (sprinklers every 40 cm) 25cm away from the window in a 120º angle against the window with a flow of 2l/minute per sprinklers. Time: 30 minutes;
- Observation during further 60 minutes, registering any water penetration if any;
- If any penetration actually happens. Further tests are recommended in order to find out if the infiltration goes through the window panel or frame.

Relevant aspects for INSITER:

- Instructions on Initial assessment;
- Instructions on the positioning of measurement point;
- Instructions on the registration of measurements.

NEN 7120+C2:2012 NL - Energy performance of buildings - Determination method

This standard gives term, definitions and the method to determine the indicator of energy performance of a building. In this general part general calculation rules are given, based on the European standards drawn up by the European Committee for a mandate for the energy performance directive of buildings (EPBD). In different part application rules are given for residential versus non-residential building and new estate versus existing works.

DIN 18197, April 2011 - Sealing of joints in concrete with waterstops

This standard applies to planning, assessment, treatment, processing and installation of waterstops.

The waterstops are used for sealing against ground moisture, non-pressing or pressing water as well as the termination of joints, and are used in the production of joints in concrete structures or –buildings made of waterproof concrete according to the standards of the series DIN 1045 in concrete.

Relevant aspects for INSITER:

- Instructions for the positioning of measurement points;
- Instructions for the installation of measurement points;
- Instructions for the monitoring und documentation;
- Instruction for the deformation stress of measurement points.

NEN 6059-1:2015 NL - Assessment of fire safety of buildings - Part 1: Initial assessment of fire safety of buildings; Part 2: Condition assessment of fire safety of buildings

NEN 6059 is a tool in order to inspect existing building uniformly. Benchmarking of buildings on the aspect of fire safety is possible. All fixed fire safety measures (e.g. fire compartment, sprinkler systems etc.) in a building are included in the fire safety scan. The fire safety scan is done in one day. The fire safety scan is limited to a visual check of the building and a check of all documents, which prove the fire safety of the building. Calculations are not part of the first safety scan.

Relevant aspects for INSITER:

- List of items to review (Initial assessment);
- Definitions on the size of the occurrence of the error;
- Definitions on the character of the error (severe/not severe; specialism, knowledge or equipment needed to correct the error);
- Classification for the importance of the error.

EN 1330-1:2014 – Non-destructive testing – Terminology - Part 1: List of general terms

This European Standard sets the general terms used in non-destructive testing, but which stem from other fields (electricity, vacuum technology, metrology, etc.) and apply in non-destructive testing. The Standard also provides the correct translation of the general terms in different languages and identifies the reference standard for each term.

Relevant aspects for INSITER:

- List of general terms that can be used to set up inspection procedures;
- Definition of the basis of the common scientific vocabulary to be adopted.

EN 1330-2:1998 – Non-destructive testing - Terminology - Part 2: Terms common to the non-destructive testing methods

This standard is concerned with terms common to non-destructive testing methods. The Standard also provides the correct translation of the main common terms (i.e. “acceptance level”, “artificial discontinuity”, “detection sensitivity” etc.) in different languages.

Relevant aspects for INSITER:

- Definition of a common vocabulary of terms that shall be adopted to define inspection and testing methods;
- Provide a correspondence of terms in different languages;
- Identify the key data to be included in the inspection procedures.

NEN-EN-13187 Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method

This standard specifies a qualitative method, by thermographic examination, for detecting thermal irregularities in building envelopes. The method is used initially to identify wide variations in the thermal properties, including air tightness, of the components constituting the external envelopes of buildings. In this standard two forms of thermography are specified: Testing with an IR camera is primarily intended for the inspection of the overall performance of new buildings or the result after a rebuilding operation. Simplified testing with an IR camera is suitable when carrying out audits, e.g. at the site of a rebuilding project or at production control or other routine inspections.

Relevant aspects for INSITER:

- Description on reporting and the presentation of results;
- The results obtained by means of this method have to be interpreted and assessed by persons who are specially trained for this purpose;
- Determination of the location of thermal irregularities and to the location of air leakage paths through the enclosure.

UNI 10721: 2012 - Technical control surveyor service for buildings and civil engineering works

The standard defines the control activities and general criteria for the award of that service, in the context of the activities of the construction industry, with particular reference to new construction work, renovation / upgrading of buildings and infrastructure. It is applicable, as a reference, in the context of all control agreements, which will specify, in detail, the applicability of the contents of this standard, taking into account the peculiarities of the intervention and the specific objectives of the commissioned control service. The standard may also provide a basis for quality assurance forms of a building, that is, the correspondence guaranteed to all or some basic requirements.

UNI 10722-1: 2007 – Building - Qualification and control of building project and design for new constructions - Part 1: Principles, general criteria and terminology

The standard outlines the criteria for pursuing conformity between the project of the work and the picture of demands made on the basis of the intervention and provides a guide to the definition and implementation of the qualification and verification building process. The standard applies to projects in the field of building of new construction work, regardless of the nature of the client, the size, functional purpose and the nature of the final work funding sources.

UNI 10722-2: 2007 - Building - Qualification and control of building project and design for new constructions - Part 2: Design planning of a single work

The standard includes the support elements for the definition of the preliminary document to the design of construction projects for new buildings. It can be used when the buyer intends to document the objectives and constraints to be placed at the base of design. The process applies to projects in the field of building of new construction work, regardless of the nature of the client, the size, functional purpose and the nature of the sources final financing of the work.

UNI 10722-3: 2009 - Building - Qualification and control of building project and design for new constructions - Part 3: Planning of design and planning and carrying out of design control in buildings works

The standard specifies the criteria, the methods and tools for the planning and conduct of audits of a building project by the standard involved. The inspectors find particular application in situations where the compliance of the project to the program should be formally checked and documented, both by the project designer, either by the customer, either by third party representatives by one or both parties, both from third parties working for the public interest.

UNI EN 16627: 2015 - Sustainability in buildings - Assessment of the economic performance of buildings - Calculation methods.

The standard establishes the methods of calculation, based on Life Cycle Cost (LCC), and other quantified economic information, to evaluate the economic performance of a building, and provides guidelines for the relationship and the communication of the evaluation results. The standard applies to both new buildings and existing buildings is consistent with the restructuring plans.

UNI 9053-1: 1987 - Construction. Structural prefabricated elements, or created site. Measurements for the dimensional geometric control of the single element.

It defines the points where to make measurements to detect individually, or through a significant number of ridges (chosen with their processes of the technique of the measures), the linear dimension deviations, and angular in shape, due to the production of prefabricated structural elements or realized in site. And 'applicable to all items that are related to the overall geometry of the forms discussed in the following paragraphs. Appendix A: Finalization and use of dimensional geometric checks of structural elements. Appendix B: Examples of coordination in the subsystem supporting structures.

UNI 9053-2: 1987 - Construction. Structural prefabricated elements, or created site. Measurements for the dimensional control of geometric elements in work.

It defines the points where we measure the nominally assembly to detect deviations. For the verification criteria it is generically refers to the measurement technique. In the presence of a significant number of reliefs (treated statistically) it can infer tolerance mounting of prefabricated structural elements (position + orientation, assuming that tracking errors negligible or separately known); in the case of performing fully-in-place structures (or in the absence of analytical data on elementary phenomena), this standard can be applied only for individual control of work for the purpose of static analysis and integration of other subsystems. The deviations are sometimes referred to only one of the orthogonal directions of the dimensional coordination, being able to clearly repeat the measurements according to the other directions.

UNI / TS 11337-3: 2015 - Construction and civil engineering - Criteria coding works and construction products, activities and resources - Part 3: collection models, organization and storage of technical information for the construction products

The technical specification, a driving character and address, is intended to indicate a structured operating model to collect and store data and technical information of the construction products.

In particular, for any construction product is provided for:

- The qualitative description (typological, technological, performance and business) cannot be defined by measurable criteria and coded;
- The quantitative description (typological, technological, performance and commercial) through a defined measurement criterion.

The model is used by the various categories of operators in conjunction with the driving model to the correct installation, installation, maintenance, transport, handling and disposal. The scope of the technical specification covers the building sector, the construction industry and its supply chain.

UNI 11532: 2014 - Acoustics in building - interior acoustic characteristics of confined spaces

The standard defines, in relation to the different intended use of the rooms, the noise indicators that can best represent the acoustic quality of the environment by offering, for each of them, the optimal values.

UNI 11367: 2010 - Acoustics in building - Acoustic classification of building units - Procedure for assessment and verification in place

The standard defines, in reference to some acoustic performance requirements for buildings, the criteria for their measurement and evaluation. On this basis, the measure also establishes an acoustic classification (with respect to each of the requirements), for the entire real estate unit (except for some types) or finally proposes a summary assessment (with a unique set descriptor index) of the requirements for real estate units. The criteria established in this standard are applicable to all units with a different use from the agricultural, industrial and handicraft.

European Directive 2012/27 / EU

The European Directive 2012/27/EU establishes a common framework of measures for the promotion of energy efficiency in Europe, aimed at the achievement of the 20-20-20 package and an improvement of energy efficiency beyond 2020. Each Member State is required to set national indicative targets for energy efficiency based on the reduction of primary energy consumption.

EU Regulation No. 244/2012 integration of the Directive No. 31/2010 on energy efficiency of buildings

Published in the Official Journal of the European Communities 21 March 2012 the Regulation contains the rules for Member States to define the optimal levels of costs required by the European Directive on energy efficiency of buildings (EPBD). In accordance with Article 5 and Annexes I and III to Directive 2010/31/EU, this Regulation establishes a comparative methodology framework in the Member States use to calculate the cost-optimal levels of minimum energy performance requirements for new and existing buildings and for building elements

European Directive 2010/31 / EU on the energy efficiency of buildings

The directive sets out in a general way how to calculate the energy performance of buildings - you can differentiate at national and regional level - and what are the factors to consider, such as thermal characteristics, the type of heating and cooling system, the shading etc. systems. In order to achieve an optimal balance between initial costs and long-term savings, the Member States should set minimum energy performance requirements, (updating every 5 years) for new buildings, existing and refurbished, for building envelope elements, for technical systems. They can be excluded from the calculation of the energy performance of the listed buildings, temporary, agricultural, residential used less than four months a year, places of worship, industrial sites, workshops, alone buildings under 50 m². But, mainly, Directive 2010/31/EU states that by 31 December 2020 all new buildings must be 'buildings to nearly zero energy'. An advance of two years, December 31, 2018, however, for all public buildings.

2.5.4 Condition assessment and inspection standards for MEP/HVAC

NEN 2767-1:2011/C1:2013 NL - Condition assessment - Part 1: Methodology and Part 2: Lists of faults

This standard describes a method to establish the technical quality of building and installation components univocally. The methodology states that the building condition does not influence business. An important part of this method is the lists of faults. These lists are applicable to constructional and building related

NEN 3682:1990 NL - Dimensional control in the building field - General rules and guidance

This standard sets generic rules for dimensional control of building elements, for the positioning on-site of building elements, spaces and joints regarding residential and non-residential buildings.

NEN 6059-1:2015 NL - Assessment of fire safety of buildings - Part 1: Initial assessment of fire safety of buildings; Part 2: Condition assessment of fire safety of buildings.

NEN 6059 is a tool to inspect existing building uniformly. Benchmarking of buildings on the aspect of fire safety is possible. All fixed fire safety measures (e.g. fire compartment, sprinkler systems etc.) in a building are included in the fire safety scan. The fire safety scan is done in one day. The fire safety scan is limited to a visual check of the building and a check of all documents which prove the fire safety of the building. Calculations are not part of the first safety scan.

NEN 3699:1993 NL - Method for measurement of net quantities of building parts, installation parts and results with specification directives

This standard describes what and how should be measured to determine quantities of parts of built up structures and the means of production to be used. Separate requirements are given for: - the determination of quantities of functional parts of built up structures, the determination of quantities of materials in built up structures, being in the design phase or as a result of the aggregation of production means: material/products, labour and equipment. This standard is applicable to any structure in both residential and non-residential sectors, in all phases of the construction process and for new built structures, renovation, restoration and demolition of these structures or part of these.

NEN 7120+C2:2012 NL - Energy performance of buildings - Determination method

This standard gives term, definitions and the method to determine the indicator of energy performance of a building. In this general part general calculation rules are given, based on the European standards drawn up by the European Committee for a mandate for the energy performance directive of buildings (EPBD). In different part application rules are given for house-building versus non-residential building and new estate versus existing works.

NEN 2686:1988 NL - Air leakage of buildings - Method of measurement

This standard describes a measuring method to determine the air permeability of buildings or parts of buildings

NEN 3660:1988 NL - Window frames - Air permeability, rigidity and strength - Methods of test

In this standard methods are described to assess façade infills, such as windows and doors, to be installed in the façades. The standard consists of methods to test: a. air permeability; b. stiffness; c. strength. The standard is applicable to vertically positioned façade infills materialised as such as they will be applied in residential building. These façade infills usually consist of a framework and infill of different materials and are intended to close a façade opening in order to from a façade. Independent from the type of material, the standard applies to moving and fixed elements in the façade. The standard does not apply to the joint between the façade infills and their surrounding construction.

NEN-EN-ISO 9972:2015 EN- Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method

NEN-EN-ISO 9972 is intended for the measurement of the air permeability of buildings or parts of buildings in the field. It specifies the use of mechanical pressurization or depressurization of a building or part of a building. It describes the measurement of the resulting air flow rates over a range of indoor-outdoor static pressure differences. This International Standard is intended for the measurement of the air leakage of building envelopes of single-zone buildings. For the purpose of this International Standard, many multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones. International Standard does not address evaluation of air permeability of individual components.

ASTM E1827-11 - Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door

These test methods describe two techniques for measuring air leakage rates through a building envelope in buildings that may be configured to a single zone. Both techniques use an orifice blower door to induce pressure differences across the building envelope and to measure those pressure differences and the resulting airflows. The measurements of pressure differences and airflows are used to determine airtightness and other leakage characteristics of the envelope.

ASTM E741-11 - Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution

This test method covers techniques using tracer gas dilution for determining a single zone's air change with the outdoors, as induced by weather conditions and by mechanical ventilation. These techniques are: (1) concentration decay, (2) constant injection, and (3) constant concentration.

NEN-EN-ISO 16283-1:2014 en - Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation

NEN-EN-ISO 16283-1 specifies procedures to determine the airborne sound insulation between two rooms in a building using sound pressure measurements. It is intended for room volumes in the range from 10 to 250 m3 in the frequency range from 50 to 5 000 Hz. The test results can be used to quantify, assess and compare the airborne sound insulation in unfurnished or furnished rooms where the sound field may, or may not approximate to a diffuse field. The measured airborne sound insulation is frequency-dependent and can be converted into a single number to characterise the acoustic performance using the rating procedures in ISO 717-1.

Heating Systems:

- **ISSO-Publicatie 31:** Meetpunten en meetmethoden voor klimaatinstallaties

  Objective: for correctly installing equipment and the correctly measuring for controlling, managing, securing and managing air-conditioning systems in buildings.
- **ISSO- Publicatie 68:** Energetisch optimale stook- en koellijnen voor klimaatinstallaties in kantoorgebouwen

  Objective: a tool to achieve substantial energy savings without large investments or disrupting company processes. The instrument is suitable for the most common installation concepts for both new and existing buildings.
- **ISSO- Publicatie 71:** Selectie van energetisch optimale warmteopwekkingsinstallaties voor kantoorgebouwen

  Objective: provides insights into the energy performance of different hydraulic circuits for spaces in office buildings.
- **ISSO- Publicatie 81:** Handboek integraal ontwerpen van warmtepompinstallaties voor de utiliteitsbouw

  Objective: describes designing heat pump systems in commercial buildings, both new construction situations and renovation projects.
- **CEN-EN 14336: 2004:** Verwarmingssystemen in gebouwen - Installatie en inbedrijfstelling van watervoerende Verwarmingssystemen;

  Objective: provides insights into heating Systems in buildings - Installation and commissioning of the water based heating systems.

Water distribution systems:

- **ISSO-publicatie 55.1:** Praktijkhandleiding legionellapreventie in leidingwater

  Objective: gives a description of the risk of collective tap water installations, offers suggestions for modifications and installation rules for the preparation of a management plan.
- **ISSO-publicatie 65:** Inregelen van ontwerpvolumestromen in warmwaterverwarmingsinstallaties'

  Objective: describes methods for tuning the design flow of hot water heating systems in residential and non-residential buildings, both new installations and for refurbishment projects.

Lighting systems:

- **NEN 12464-1:** Licht en verlichting - Werkplekverlichting - deel 1: werkplekken binnen

  Objective: specifies requirements for lighting solutions for most indoor work places and their associated areas in terms of quantity and quality of illumination. In addition recommendations are given for good lighting practice.
- **NEN 12464-2:** Licht en verlichting - Werkplekverlichting - deel 2: werkplekken buiten

  Objective: specifies lighting requirements for outdoor work places, which meet the needs for visual comfort and performance.

Ventilation systems:

- **CEN-EN 12599:** Ventilation for buildings Test procedures and measuring methods for handing over installed ventilation and air conditioning systems

  Objective: enables the choice between simple test methods, when sufficient, and extensive measurements, when necessary.

Electrical installations:

- **NEN 3140:** Bedrijfsvoering van elektrische installaties – Laagspanning

  Objective: specifies requirements for the safely managing of electrical installations and electrical equipment- low voltage.

- **NEN 1010:** Elektrische installaties voor laagspanning - Nederlandse implementatie van de HD-IEC 60364-reeks

  Objective: specifies requirements for electrical installations for low-voltage - Dutch implementation of the HD-IEC 60364-series.

Other relevant norms:

- **Fume cupboards**
  - NEN-EN 12175: 'Zuurkasten'
  - NPR 4500: 'Zuurkasten - eisen, beproeving en aanbevelingen bij plaatsing, gebruik en onderhoud van zuurkasten in laboratoria - Toeliching bij NEN-EN14175 Zuurkasten'.
  - Arbo Informatiebladen AI 18 en AI 19
  - CEN/TS 14175-5: 'Aanbevelingen voor installatie en onderhoud'.
  - NEN EN 12469: 'Biotechnologie – Prestatie-eisen voor microbiologische veiligheidswerkkasten'.
- **Cooling systems and internal cooling spaces**
  - ISSO-publicatie 31: 'Meetpunten en meetmethoden voor klimaatinstallaties'.
    Model Building Specification for Design, Installation, and Commissioning of Insulated Envelopes and Insulated Floors for Temperature controlled and Ambient Environments', International Association for Cold Storage construction (June 2003).
- **Automatic control systems**
  - ISSO-publicatie 31: 'Meetpunten en meetmethoden voor klimaatinstallaties'.
  - ISSO-publicatie 68: 'Energetisch optimale stook- en koellijnen voor klimaatinstallaties in kantoorgebouwen'. ISSO-publicatie 69: 'Model voor de beschrijving van de werking van een klimaatinstallatie'.
  - CEN-EN 50491: 'General requirements for Home and Building
- **Water installations**
  - NEN 1006
- **Firesafety**
  - NEN 2535 Brandmeldinstallatie
  - NEN 2575
  - Ontruimingsalarminstallatie
  - NPR 2576 Functiebehoud
  - bij brand
- **Emergency lighting**
  - NEN 1010
  - ISSO - instructieboek noodverlichtingsinstallatie
  - NEN1898 5.2 – 5.6 (only sections 5.2 - 5.6 of the norm are relevant) ARBO 3.7 en 3.9

At the end of this analysis it is important to suggest that the next INSITER guidelines (D1.2 and D1.3 at M36), should present the following contents:

- A clear definition of the building components and key data to be assessed (window, or façade element etc.);
- Reference to a common vocabulary;
- Description of which tool to use in which situation;
- Instructions on the operation of tools;
- Instructions of the positioning (and installation) of measurement points;
- Instructions of how to register the measurements.

3. MOST FREQUENT CONSTRUCTION ERRORS

The chapter identifies and defines the INSITER investigation field in terms of building systems and prefabricated components. First the main technological systems are examined and classified.

We describe what prefab is intended in the building sector: we provide some description about prefab systems, divided by building elements and MEP/HVAC components and summarize its advantages and disadvantages.

We then offer reasons why the use of prefab components may become prevalent in Europe, thanks to new materials and above all the novel processes. Finally, we shortly describe the most common construction errors that can actually be identified for each prefab systems

The shortlist contains a group of currently existing construction process errors. They have been evaluated following the regular timeline for projects from design to prefab, mounting on site and maintenance.

The shortlisted construction process errors are:

1. Phase 0 not appropriately worked out: Especially the programming of projects setting the boundaries in terms of costs, time and quality with the clients are done insufficiently and the total quality is under-defined, often the experts/the personnel chosen are not fitting to the project demands, this is even more crucial in terms of renovation projects as the SotA analysis of the existing building and the design for the renovation have to be in line, structural reliability assessment is not done the right way, too.
2. BIM clash detection not applied/bad applied in terms of underdeveloped BIM model: No aggregated holistic and consistent data model with design and engineering details available, as a result the components might be badly prefabricated
3. Dimensional accuracy of the prefab components is not used as a benchmark in the design, built as designed and mounted on site overlay data model, joints are not matching with the needs of the tolerances and there are design and technical defects.
4. Assembly –virtual pre-assembly at the factory- is not done causing lot of time cost and quality problems on site. The logistics of prefab components might cause unforeseen damages and there is no benchmark for the use or withdraw of these elements.
5. Air leakage problems created by wrong/not appropriate sealing of doors/windows, component to component connection or component to other bearing (existing in renovation sector) structure or envelope building components.
6. The pre-assembly of the MEP/HVAC components is done in a wrong way, the plug and play connections on site are not working, missing quality check of components that are built in causing lot of demand for rectifying these defects.
7. Not appropriate commissioning especially of the MEP/HVAC system and its components, no user behaviour oriented steering opportunity of the system, no continuous monitoring in order to have an ongoing calibration.
8. Bad qualification of mounting workers on site causes eg. wrong positioning of prefab elements, no appropriate inspection after the construction work has been done.

3.1 Technological systems of Energy-efficient Buildings (EeB)

This section discusses the division of building systems into levels of the construction or into individual components such as roof, facades etc. or, from another perspective, according to work packages of the trades involved in the construction. The classification can help our research in identifying the elements that will be addressed and further analysed in the INSITER framework, especially during the development of self-instruction and self-inspection procedure for different use cases.

The classification of building elements is an integral and key component of some national standards (UNI 8290 - part 1 and 2 in Italy, ASTM E1557-97 in the U.S.), even if there is a lack of common European standard that could provide a point of agreement on design elements for all project stakeholders. According to the both building technology state-of-art and the aforementioned standard references, two main different classifications of building elements can be defined.

The first classification proposes to divide a building by systems, sub-systems, modules and elements, following a hierarchical structure. A system is a complex and determined structure of many modules that are connected to each other in order to create an organic “whole”. Distinguishing the modules of a building is simple, as long as the separation of functions reflects separated modules that are assembled from individual elements. In this perspective, the whole building can be subdivided into:

- **Systems:**
  - Primary systems, consisting of load bearing walls or the structural frame of the building, decks/slabs;
  - Secondary systems, consisting of the building envelope (façade, walls, ceilings, roof and floors)
- **Modules:** façade modules, windows, doors, stairs, roof systems, etc.
- **Elements:** façade panels, glass panes, windows frames, roof beams, etc.

Each major group of elements can also be subdivided into more detailed groups.

The second classification is based on design/construction work packages. Elements, as defined here, are major components common to most buildings. Elements usually perform a given function, regardless of the design specification, construction method, or materials used, as follows:

- **Building envelope;**
- **Interyor systems;**
- **Load bearing elements;**
- **MEP-HVAC**.

These two classifications serve as a consistent reference for analysis, evaluation, and monitoring during the feasibility, planning, and design stages of buildings, since they works as the common thread linking activities and participants in a building project from initial planning through operations, maintenance, and disposal. They also enhance reporting at all stages in construction—from feasibility and planning through the preparation of working documents, construction, maintenance, rehabilitation, and disposal.

The identification of different technological units that interact one with each other is crucial in the analysis of Energy-efficient Buildings (EeB) or Intelligent buildings, since such kind of construction presents a higher level of complexity and integration than traditional buildings: dealing with EeB means namely to clearly identify 1) the constituent elements of the buildings and 2) the mutual interactions between them, in each stage of the design and construction process.

These issues have become urgent by the new European legislation, in particular the 2010 Energy Performance of Buildings Directive (EPBD) and the 2012 Energy Efficiency Directive (EED).

The Energy Performance of Buildings Directive sets the framework and boundaries to proceed along this track (EC official site, Oct 2014):

- EU countries must establish inspection schemes for heating and air conditioning systems or put in place measures with equivalent effect;
- All new buildings must be nearly Zero Energy Buildings by 31 December 2020 (public buildings by 31 December 2018);
- EU countries must set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls, etc.);
- EU countries have to draw up lists of national financial measures to improve the energy efficiency of buildings.

Under the Energy Efficiency Directive (EC official site, Oct 2014):

- EU governments should only purchase buildings which are highly energy efficient;
- EU countries must draw-up long-term national building renovation strategies which can be included in their National Energy Efficiency Action Plans.

In this context, INSITER research is oriented to improve the quality assurance and energy efficiency performance by proposing a more efficient inspection methodology of intelligent buildings with a significant use of prefabricated components. The integration in the design and construction process results of procedures for self-instruction and self-inspection can improve communications and coordination among all project participants, an accelerated design, and significantly increased productivity on site.

Given that, INSITER framework organises the prefabricated components in two main groups with the above-mentioned functional and technological classifications. These two groups, and their specific performances, shall be the focus of our analysis:

1. **Prefab building components**
    a. of the building envelope system;
    b. of the interior system;
    c. of the load bearing system.
2. **Prefab MEP-HVAC systems**
    a. Heating and cooling installations based on hydronic distribution circuits;
    b. Ventilation systems based on central air handling units with a duct system for air distribution;
    c. Control system / building automation system.

3.1.1 Building components and prefabrication

The aforementioned building components play different roles within the building overall performance:

a. "Building envelope system" (roof, façade and basements) is the key element to address in order to achieve the energy efficiency both in new construction projects and in the retrofitting of buildings, where the façade represent the largest part of the heat transmission surface and includes a number of critical components (like windows, balconies, ventilation units, etc) and thermal bridge phenomena.
b. "Interior system" is mainly related with building systems and also affects the physical and emotional well-being of the building occupants, and the indoor environmental quality.
c. "Load bearing system" does not directly affect the energy performance of a building but it represents the essential condition for the correct assembly of all other building and system components.

All these different functions shall be strictly related within the prefab context: in general, the term prefabrication can apply to any construction method where a significant part of the construction takes place off-site in a factory that produces relatively large, complex pieces that are then assembled at the site into the finished building.

Since prefab is such a loosely defined term, it can be helpful to briefly define the spectrum of construction methods ranging from completely off-site to completely on-site. Integral prefabrication refers to the complete assembly of an entire building in a factory, while the more common version is a hybrid, since the building components are produced off-site and then assembled with parts of buildings constructed using traditional on-site techniques. At the extremes, manufactured homes (commonly called trailer homes) are brought to the site almost completely finished, while in traditional masonry, wood, steel or concrete construction, houses are built almost completely on-site from several basic materials. In this perspective, prefab within INSITER framework fits in the middle of this continuum: it bridges the gap between manufactured buildings and traditionally built buildings, offering many of the advantages and opportunities of each category.

According to their characteristics, the three aforementioned building systems (building envelope systems, interior systems, load bearing systems) may belong to one of these prefabricated systems:

- **Open systems:**

  Open systems are those that allow to use building components from different manufacturers and to combine them together to realise a building, seeking to identify components with a high level of compatibility, above all from the dimensional point of view. By combining a small number of manufactured systems into one comprehensive approach, there is a significant reduction in the design of an entirely new system, and there is an increased and long-term applicability. The advantage of open prefabrication consists of being able to access a wide range of building components, provided by different suppliers, and to provide a variety of formal and detailed solutions. The main shortcoming lies in the risk of non-compatibility among different systems, with a reduction of the performance of the assembled components on site if compared with the technical characteristics of each single product.

- **Closed systems:**

  The current trend in prefab is to create direct connection between different manufacturers of prefab elements, to develop mutually compatible products. In such case, we can speak of closed systems. Closed prefab systems in building sector draw their inspiration from industrial and automotive design and propose standard systems (even entire dwellings!) that can be purchased from a catalogue, in general organised in series and composed of different models, allowing some minor changes in finishing and materials in order to personalize the "product". The advantage of closed systems is to perform an extremely detailed quality control in each stage of the production (off site) and installation (on site) process. The assembly instructions and the interface between the different elements are subjected to a large-scale monitoring, which minimizes errors. The integration between the building and MEP/HVAC systems is generally addressed already in the design phase. However, such systems show poor flexibility and are not suitable to completely address the construction sector request, which presents an extreme variety of demands. Closed systems are feasible only in the case of specific types of buildings and of limited size. They are also of little use in projects, such as renovation and retrofitting of existing buildings.

- **Hybrid systems:**

  Hybrid prefab proposals combine the flexibility of and open system and the use of a limited number of basic compatible components, typical of a closed system. In figurative terms, such approach is similar to LEGO or MECCANO systems. Within hybrid systems, some companies adopt modular systems only for prefab elements (i.e. curtain wall), and optimise them in technology, while the interface with the other building elements is designed and developed project by project. This approach has the advantage of providing more customized products, even if the main problem lies in the detailing and in the lack of reference procedures to assess and verify the actual interaction of different systems in terms of performance.

3.1.2 MEP-HVAC components that influence energy efficiency

The section presents a long list of the main MEP-HVAC components that influence the enegy efficiency in consideration of three main categories as follow.

1. Heating and cooling installations based on hydronic distribution circuits

1. **Heat exchangers** do not meet the specs of the manufacturer. They may be 10 -20% too small sized. The American Refrigeration Institute (ARI) and Eurovent have standards and guidelines to ensure that calculation and reality of the heat exchanger performance are aligned.
2. **Counter flow heat fluid/fluid exchangers (plate heat exchangers)** should be specified in such a way that a certain amount of fouling is taken into account. ARI and Eurovent give guidelines for this.
3. **Heat pump** performance should be specified for full load and partial load conditions. In practice a difference between suppliers' specs and measured performance may occur. ARI and Eurovent have standards and guidelines to avoid this.

4. **Incompetent engineering, selection and control of a heat pump** are the main cause of underperforming of the heat pump.
5. **Sub-soil heat and cold storage systems** should be designed properly, especially the closed loop storage systems. There are no components in them, which are very critical with respect to energy
6. **Buffer tanks** may be so called mixed buffers or thermally stratified buffers. Both have very different functions and design rules. If not designed correctly, the flows and temperatures in the hydronic system will not be in control, causing non-optimal performance of heat and cold generation components.
7. **Circulation pumps** should meet the European Norm IEC 60034-30-2008. Electric motors should meet IE3 since 1 January 2015.
8. The main causes of underperforming circulation pumps are:
    a. Bad engineering / pump selection: in most cases too big pumps and not enough attention for minimum load conditions.
    b. No or no adequate speed control for the pump.
    c. Too much settings and adjustment issues in the control unit of the pump unit. Holds especially fort he bigger circulation pumps.
9. **Corrosion** in hydronic circuits may occur as a result of ***too small*** expansion buffers in the circuit and/or ***incorrect position*** of the expansion buffer in the circuit.
10. Adjusting valves are necessary for balancing the hydronic circuit. Lack of know-how of engineers and construction workers can lead to construction errors. Many of these valves are:
    a. Not the right size (too big, too small);
    b. Not adjusted at the correct setting.
11. Control valves are used to adapt the flow in such a way that:
    a. An intended supply temperature behind a mixing point is achieved;
    b. A heating of cooling capacity of a heat exchanger is adapted.

    Many control valves are not functioning well, causing problems with temperature levels in the hydronic circuits, which in turn deteriorate the efficient functioning of heat or cold generation components. Main reasons are:
    c. Lack of know how at the engineer;
    d. Lack of attention during realisation;
    e. Bad quality / short lifetime of the valves, especially the actuator motors.
12. A heating of cooling capacity of a heat exchangers
13. Hydronic circuits are often not designed and/or build correctly, resulting in bad functioning distribution circuits, lack of heating or cooling capacity. In The Netherlands there are plenty of guidelines from ISSO, however they are applied much too little, due to:
    a. Lack of know-how, engineering people do not understand what they read;
    b. Lack of attention or time to do the job properly;
    c. Lack of engineering tools for designing and simulation of hydronic circuits.

2. Ventilation systems based on central air handling units with a duct system for air distribution

Components that influence the energy efficiency:

1. Central air handling units are the most importants part:
   a. Air velocity in the unit strongly influences the required fan capacity and electricity consumption;
   b. Fan efficiency depends on fan design, applied motor (see above) and speed control;
   c. Type of applied air filters influences energy efficiency.
2. Design, realisation and balancing of the duct system:
   a. Same remarks as for hydronic systems.

3. Control system / building automation system

1. The system consists of the following main parts:
   a. Control units with i/o facilities, calculation power and data storage;
   b. Sensors;
   c. Software for control, protection of the installation in case of component failure, power failure etc. and data monitoring and storage.
2. The automation system is the source of many faults and disfunctioning of systems:
   a. Sensors are not correctly sized (especially flow sensors);
   b. Sensor quality / specification do not meet the requirements;
   c. Sensors are not correctly fitted;
   d. The signal from the sensor is not correctly processed in the control unit;
   e. The control, protection and monitoring strategy is incorrectly specified and/or implemented;
   f. The setpoints are changed and not documented;
   g. Insufficient testing and verification of the automation system;
   h. Lack of know-how at designers and on-site workers;
   i. Poor information transfer within the value chain, from designer to installer to automation company to software implementation employee.

3.1.3 Prefab components in terms of process innovation: main benefetis and disadvantages

In the last decades the use of prefabricated elements has returned to a central position in the building sector. The renewed focus on prefabrication mainly depends on the needs of adopt industrial approaches to building production, using digital tools and processes borrowed from other manufacturing sectors.

The theme of prefabrication is primarily oriented to *process innovation*, since the aim of prefabrication of building elements is to optimize industrial processes (manufacturing in the factory) and construction processes (on construction site) by introducing digital tools.

Compared to traditional construction processes, prefabrication aims at reducing costs without compromising quality and facilitating installation/dismantling/reuse of components. Industrial processes, to which even the construction process can be assimilated, aim to integrate "traditional" consolidated technologies to innovative and digital technologies: this is exactly the area where INSITER research can nowadays contribute, i.e. updating building traditional techniques with respect to novel digital tools.

The renewed interest in prefabrication depends on several reasons, since prefab offers a number of advantages:

- Gain on construction time and to improve on site safety. Accelerating the time schedule is suitable for new construction but also for renovation projects, while the building is being occupied.
- Reduce material costs, since off-site fabrication benefits from specialization and economies of scale;
- Reduce labour costs and improved manufacturing efficiency;
- Provide higher quality materials and tighter specifications, with a deeper quality control (off-site);
- Obtain lower environmental impact, since the off-site manufacturing processes optimise and reduce the amount of waste generated during fabrication (off-site) and assembly (on construction site), based on Life Cycle Assessment and Carbon Footprint of Products;
- Reduce impact of the work site: less noise pollution, reduced risks related to the use of construction equipment, minor pollution for the environment (i.e. air, water etc.), reduced traffic to and from the work site;
- Respect scheduled installation time and replicability potential: in a report produced by *McGraw-Hill (2011)* on prefabrication, it was stated that prefabrication in two-thirds of companies that use prefabrication experienced reduced project schedules;
- Enhance quality standard guaranteeing optimum building performance, above all in terms of energy performance, for the installed prefabricated modules and their integrated components.

On the other hand, it is worth examining some general difficulties related to the use of prefab systems in the construction sector, in order to identify the areas where further research and improvement is needed:

- Design limitations and poor flexibility, since certain designs may stretch the limits of the prefab components chosen for a project;
- Lack of workers skilled in the construction methods of prefab systems;
- Little cost advantage, since the labour and material cost advantages of above mentioned prefab elements over traditional construction depend on economies of scale;
- Inability to determine whether the actual performance of the prefab element installed on-site is consistent with the performance of the product as determined off-site.

The shortcomings related to each building system will be detailed in the next section.

3.2 Common construction errors of prefab buildings affecting energy efficency

In order to develop an innovative INSITER methodology (objective n°3 of the project) it is necessary to identify the most frequent errors committed during the construction phase of the process (on-site). The list of errors is presented in the following pages. Despite this, analysing the complete design and construction process it is possible to define several errors not only related to the construction task (Fig. 15). Nevertheless, INSITER supposed that all "design tasks" are completely perfect (no errors are committed). For this reason our attention for next actions will be localised only to the definition of the construction errors on-site that could be included and implemented in a specific construction errors data-base.

Design errors: Errors during the design phase of the process	
Task: Concept design	Missing key persons in the project team
	Missing or incoherent project programme (process)
	No definition of the sustainability requirement expected (e.g. energy requirements)
	No description of the user needs and/or quality objectives (e.g. client requirements)
	No explanation of the project budget
	Flawed preliminary analysis of the site (e.g. weather data, temperature, wind, solar, shading)
	No definition of BIM procedures
	Missing a responsible of the BIM Model (BIM Model Manager)
	Insufficient qualification of team members, expertise missing
	Architectural concept design incompatible with the local climate condition
	No definition of the preliminary cost information (based on the project budget)
	Architectural concept design incompatible with the user needs and/or quality objectives
	No outline proposal for the structural design
	No outline proposal for the building services system (MEP-HVAC)
	No preparation of a sustainability strategy
	No consideration of a construction strategy (offsite fabrication, developed health, safety strategy)
	Insufficient communication from the key persons
	Underdeveloped BIM Model
	Incoherent BIM Data (environmental performance and area analysis)
	Missing BIM Data (e.g. energy tariff, construction cost, lifecycle cost, U factor, etc.)
	No identification of the key model elements (prefabricated components)
	Architectural concept design incoherent with the regional, land or national building laws e.g. in terms of building physics
Task: Detail design	No use of the BIM data propose
	Developed design incompatible with the local regulation
	Developed design incompatible with the user needs and/or quality objectives
	Developed design does not follow the estimated budget cost
	Developed design does not respect the sustainability strategy defined
	Developed design incomplete (missing drawings/documents)
	Incongruence of the structural design
	Incongruence of the building services system (MEP-HVAC)
	Insufficient communication from the key persons
	No data sharing and no integration for design coordination and detailed analysis
Task: Final design	Incorrect detail drawings
	Incomplete detail drawings (no information, no drawing, etc.)
	Recommendation of unsuitable materials, building components and/or other elements
	Proposed incorrect MEP-HVAC
	Structural calculation errors
	Thermal transmittance calculation errors
	Insufficient communication from the key persons
	Flawed or incomplete building contracts
	Clash detection –analogue or digital or both- process not implemented
	Bad tolerances management

Construction errors: Errors during the building construction phase of the process	
Task: on-site	Onsite manufacturing in conflict with the design
	Onsite manufacturing in divergence with the construction programme
	Irregular site inspection by the construction manager
	Assembly of damaged building components
	Incorrect assembly of building components
	Improper installation of windows and doors
	Improper installation of MEP/HVAC systems
	Assembly of building components differing from the technical design
	Lack of appropriate coordination of the work
	Omission or changes of constructive elements
	Incorrect location of the building components
	Geometric problem of the building component (e.g. panels)
	Mistakes during the assembly of the building components (e.g. leakage, water infiltration, damp)
	Flawed execution by the construction workers
	Misinterpretation or incorrect use of the documentation
	Interference with other activity
	Installation of unsuitable material
	Material change
	Documentation without distribution
	Inaccurate use of materials
	Error with measurement and testing equipment
	Incorrect stoking
	Non-qualified personnel (first and subcontractor)
	Broken pipelines
	Climate interference: rain, temperature (e.g. panel faced)
	Coating defect (e.g. panel faced)
	Increased loads (e.g. slab)
	Incorrectly sealed (e.g. panel faced, floor, services)
	Ongoing iteration process –model versus realized on site- between expected 100 % quality model and realised model missing
	Crisis intervention model to cover not calculable internal and external influences missing
Task: off-site	Offsite manufacturing in conflict with the design
	Offsite manufacturing in divergence from the construction programme
	Geometric problem of the building component (e.g. panels)
	Misinterpretation or incorrect use of the documentation
	Bad realisation of the building components
	No undertake testing
	Documentation without distribution
	Mishandling material and incorrect transport
	Incorrect manufacturing
	Flawed testing
	Error with measurement and testing equipment
	Incorrect stoking
	Non qualified personnel (first and subcontractor)
	Error in the order (material, building components, etc.)
	Did not check the material against the receipt

Use errors: Errors during the maintenance intervention or when the building is in use	
	Incorrect use of the MEP/HVAC by the end users
	No ventilation and/or air exchange inside building
	Lack of building maintenance
	Creation of unauthorised intervention
	Incongruent BIM Model data
	No assistance for building user during initial occupation period
	No user manual and training for use and maintenance issues
	No monitoring tool for ongoing quality check in use phase as a part of FM creating monitoring and maintenance action plans
	No monitoring of indoor qualities e.g. air quality

Fig. 15 – Errors in the main task of the process

3.2.1 Common construction errors in the building envelope

The building envelope is the physical separator between the conditioned and unconditioned environment of a building including the resistance to air, water, heat, light, and noise transfer.

A good building envelope adopts appropriate materials with the external climate condition in comparisons to the expected indoor environmental performances (acoustic, thermal, humidity, and lighting).

The building envelope normally consists of roof, sub-floor, exterior doors, windows and building facades or external wall.

Considering the industrialized building realized with prefab components several errors can be committed during the construction and manufacturing task. The subsequent list proposes the main errors and the problems derived.

Offsite manufacturing in conflict with the design

The manufacturing components of the building envelope are different (e.g. incoherent surface finishing or materials, improper inner materials of sandwich panels, incongruent geometric dimensions, etc.) in comparison to the final design (technical drawings and specifications) elaborated by the design team. These errors cause delay of the construction time, increase of the construction costs, and potentially cause errors in the on-site assembly process resulting in building quality and energy performance gaps.

Poor manufacturing of the buildings components

The incorrect technical manufacturing of the envelope building components can cause defective components characterised by technical attributes differing from the expected performances. Windows with different thermal transmittance, panel façades with incorrect external joints, varying thicknesses of the façade panels as well as inconsistent insulation with dissimilar thermal conductivity are examples of the possible manufacturing problems that could impact building energy performance and quality.

Onsite manufacturing in conflict with the design

The building envelope construction is different in comparison to what was proposed and does not follow the specifications of the final design. The technical problems require construction adjustments which cause cost increases as well as delays in the construction time. If the construction manager does not recognise the incongruent building realisation, the results achieved and the building performance will be that of another one from the proposed project.

Assembly of damanged building components

The transportation of the building components, the movement as well as the incorrect stock on-site could cause damage to the components (breakage, surface abrasion, etc.). Assembling damaged building components could cause the building performance to differ from that of the expected result originating from the architectural, technical and structural point of views. The construction workers as well as theconstruction installers must check the quality of the building components prior to the installation.

Incorrect or mistaken assembling of the building components

The incorrect assembly of the building components, particularly concerning the joints between the various parts that link the building façade and the roof (e.g. windows/doors to façade, panel façade to panel façade, wall to slab, and façade to roof) cause several building defects. Air leakages, water infiltrations, damp, high thermal transmittance, thermal bridges, horizontal and vertical alignments are just a few examples of the possible technical problems.

Poor component locations or improper installation

The importance of a correct installation of building components is extremely significant in order to maintain the expected performance of the construction. Similar geometric building components of the envelope (e.g. windows, doors, panel façade) have appropriate technical characteristics (the most important being the thermal transmittance) that demand installation in a specific location following the indication of the final design elaborated by the design team. The professional role of the construction workers and the monitoring by the project manager are critical.

Misinterpretation of incorrect use of the documentation (e.g. technical drawings)

The technical knowledge background of the construction workers is very important for realisation of the building however, the understanding of the final design elaborated by the design team is also of value. The misinterpretation or incorrect use of the technical documentations could cause other construction errors. The choice of a construction company (and eventually sub-contractors) influence by the technical point of view is of utmost importance in order to obtain the expected building performance. This is one of the issues that will be tackled in the upcoming guidelines.

Omission or assembly of building components differing from the final design

The assembly of building components differing from the technical design (e.g. different sandwich panel, different inner insulation, different windows, etc.) will alter the energy performance of the building. Only the design team and the project manager are authorised to propose a change of the building components. The construction company is not authorised to take initiative that will change the expected building performance.

Geometric problems of the building components

In order to seal the building envelope it is necessary that all building components are properly realised from the geometric point of view. Differing geometric shapes and dimensions (vertical and horizontal) of the envelope components in comparison to the technical drawings can cause water infiltrations, air leakages and acoustic problems. The alteration of the geometric dimension could be the result of incorrect off-site manufacturing, improper stock, bad handling or incorrect transport.

Installation of unsuitable material

The monitoring of the component quality that arrives on-site is very important in order to preserve the original requirements. The installation of deteriorated and unsuitable materials, especially in the building envelope, is not consistent with the main aims of the project strategies. Moreover, it will accelerate the building's degradation. It is suggested to assemble only certificated building components with congruent quality.

Windows and doors incorrectly sealed on-site

The correct assembling of windows and doors on external walls as well as skylights in roofs is incredibly important in order to reduce the airflow. In fact, the high-energy performance of a building is directly related to the reduction of thermal dispersions.

Irregular site inspection by the project manager

The regular inspection on the building construction site by the project manager is fundamental in order to control the realisation of the building quality. Despite this, sometimes it is not sufficient enough to define the expected quality of the building, in particular in terms of energy efficiency. The use of old and inadequate instruments or equipment to inspect the activities of the construction workers could also cause a differing building performance in comparison to the expected design.

3.2.2 Common construction errors in the interior systems

The interior systems of prefab buildings are in generally vertical (walls or doors) or horizontal (floor) partitions that separate adjacent rooms usually characterized with the same indoor thermal condition. For this reason is possible to say that the most frequent errors of the interior systems are related to acoustic problems.

Despite this sometimes the interior systems are connected with the building envelope (façade and/or roof) in this case the correct manufacturing (e.g. connection from different parts) is essentially to obtain the expected indoor performance.

The subsequent list proposes the main errors and the problems derived during the construction and manufacturing task of the interior systems.

Off site manufacturing in conflict with the design

The construction of the interior partitions (vertical and horizontal) are different in comparison to the project proposed and don't follow the indication of the final design. The technical problems require construction adjustments; the costs increase as well as the construction time. If the construction manager does not report the incongruent building realisation, the results achieved will be different from the expected project.

Assembly of damaged building components

The transportation of the building components, the movement as well as the incorrect stock on-site could cause damage of the components (breakage, surface abrasion, etc.). From the technical point of view, the indoor performance will be different than the expected result if the building components assembled are damaged. The construction workers as well as theproject manager must check the quality of the building components before the installation.

Bad component locations or improper installation

The importance of correct installation of the interior building components in the right position is significant in order to preserve the expected performance. Similar geometric interior building components (e.g. prefab interior partition wall or doors) have appropriate technical characteristics that demand the installation in a specific location following the indication of the final design elaborated by the design team. The professional role of the construction workers and the monitoring of the project manager are very important.

Misinterpretation or incorrect use of the documentations (e.g. technical drawing)

The technical knowledge background of the construction workers is extremely important in order to realise the building, but it is also equally important that they be of capable of understanding the final design elaborated by the design team. The misinterpretation or incorrect use of the technical documentations could cause other construction errors. The choice of a construction company (and eventually sub-contractors) informed by the technical point of view is very important in order to obtain the expected building performance.

Omission or assembly of building components different from the final design

The assembling of building components differing from the technical design (e.g. different stairs, different interior partitions walls, different doors, etc.) will modify the architectonic quality of a building. Only the design team and the project manager are authorised to propose a change of the building components. The construction company is not authorised to take initiative that will change the expected building performance.

Geometric problems of the building components

All building components must be articulately realised from the geometric point of view following the indications of the technical drawings. Differing geometric shapes and dimensions (vertical and horizontal) of interior components cause, for example, acoustic problems. The alteration of the geometric dimension could be the result of incorrect off-site manufacturing, improper stock, bad handling or incorrect transport.

Installation of unsuitable material

The monitoring of the component quality that arrives on-site is of utmost importance in order to preserve the original requirements. The installation of deteriorated and unsuitable materials is not aligned with the main aims of the project strategies. Moreover, this will accelerate the building degradation. It is suggested to assemble only certificated building components with congruent quality.

Incorrect manufacturing of the interior stair

The stairs are one of the most important internal prefab components of the building. The prefab scale can be realised in precast system, in steel or in wood technologies. The incorrect manufacturing causes delay of the construction time as well as an increase of the construction costs.

Incoherent assembling between the interior vertical partitions and the external façade

The vertical interior partitions (walls) must be joined with the external façade. This kind of construction error can cause exchanges between different interiors spaces (e.g. acoustic problems, thermal exchange, indoor air quality, etc.), and possible performance gaps in the connection area in respect to the surface of the external vertical wall.

Incoherent assembling between the vertical interior partitions with the horizontal internal partitions

The vertical interior partitions (walls) have not been joined with the horizontal internal partitions. This construction error can cause an exchange between different interiors spaces (e.g. acoustic problems, thermal exchange, indoor air quality, etc.).

Incoherent manufacturing on-site of the interior building components

The incorrect manufacturing of the interior building components, in particular, considering the joint from the same system (vertical partition to vertical partition and horizontal partition to horizontal partition) can cause: static problem for the occupant's safety, alteration of the interior surface, acoustic problem, etc.

3.2.3 Common construction errors in the load-bearing systems

Common construction errors in loadbearing systems arise due to either inadequate structural design or lack of attention to relatively minor details, related to the structural components or to the interface between structures and other building systems. Inadequate structural design can be prevented by thorough and careful review of all design procedure and calculations: this aspect is significantly reduced in the design of the prefabricated components, since the dimensional control is carried out systematically for each kind of product. On the other hand, the challenge is to integrate the different production stages, from design to assembly, in order to high reducing construction time, reducing total cost, reducing the material waste and increasing quality of buildings.

Incorrect provision regarding assembly tolerances of different building systems

Each prefabricated product is characterized by specific assembly tolerances. If these tolerances are not interfaced with each other, gaps and/or construction mistakes may occur on site, especially regarding façade panels, and cannot be compensated during the construction phase. Therefore, incorrect or missing offsite planning of prefab system tolerances can result in poor realization, gaps and voids that can impact building quality and envelope energy performance.

Uncertainty of product technical specifications

In prefabricated systems, the decoupling point can be located at the interface between the manufacturing phase and the construction assembly. Since each project can be considered one-of-a-kind, the lack of detailed specifications can lead to uncertainty in the assembly procedure, use of improvised and ineffective onsite solutions, with a lower building quality and an increase in construction costs.

Incorrect or insufficient details

One of the crucial points of construction process lies in lack of details: poor details can cause localised concentration of high stresses in structural members, even if the design is adequate enough to meet the requirements. Poor details may not lead to structural failure, but it can become the cause of deterioration of building components. The preparation of technical drawings and appropriate instructions can prevent these errors in the construction phase and can be used to properly instruct the workers inspectors onsite.

Incorrect assembly sequence

Construction errors can result from an incorrect and inconsequential assembly procedure of load bearing systems and envelope. In fact, the assembly of the envelope is related to the type of adopted structural system and to the mutual position of the envelope and the structure itself (inserted, cantilevered, and suspended). For instance, in the case of reinforced concrete structures and curtain panels inserted within the structural frame, the envelope shall be installed from the top downwards and not vice versa, to offset occurred deflection. Errors in the assembly sequence can cause serious damage to the building and may depend on the inexperience of the workers or the lack of instructions.

Insufficient accuracy in the assembly of the structural elements

The incorrect positioning of load bearing components, especially in ordinary or pre-stressed reinforced concrete, can result in mismatches and misalignments that lead to incompatibility in the subsequent installation of secondary elements (i.e. envelope, interior systems). These kinds of errors can cause difficulties and potential damages in the installation of the envelope components and accessories.

Incorrect or poor provision for drainage systems and gaskets

Poor attention to the details of draining may result in infiltration and ponding of water in load bearing components, especially in the connections and joints with the façades. This ponding may result in leakage or saturation of concrete and deterioration and swelling of metal (i.e. rust). Leakage may result in damage to the interior of the structure or in staining and encrustations on the structure. Saturation may result in severely damaged concrete if the structure is in an area that is subjected to freezing and thawing. These errors cause significant deterioration in the overall building quality.

Incorrect or poor realization of the expansion and secondary joints

Inadequately expansion joints may result in spalling of load bearing systems, especially adjacent to the joints. The full range of possible temperature differentials that a reinforced concrete or a metal structure may be expected to experience should be taken into account in the specification for expansion joints. Leaks can form at joints in prefabricated components and at the connection with load bearing systems. The lack of a clear hierarchy of primary and secondary joints can lead to defects in the structure and related elements.

Installation of incompatible materials

The use of materials with different properties (modulus of elasticity or coefficient of thermal expansion) adjacent to one another may result in cracking or spalling as the structure is loaded or as it is subjected to daily or annual temperature variations. The installation of such materials may cause cracking and then alter the energy performance of the envelope.

Installation of rigid materials to seals the joints

The use of rigid adhesives to seal gaps between load bearing systems and other elements can cause, over time, the creation of cracks and or deformations, resulting in undesired thermal/acoustic dispersions. These errors can accelerate the envelope degradation.

Poor or mistaken reinforcement at corners, openings or other crucial elements

The correct implementation of the singular points of structural systems and connections is crucial to achieve an adequate technical quality. For instance, corners and openings tend to cause stress concentrations that may cause cracking and/or deformations. Abrupt changes in section may cause stress concentrations that may result in cracking, especially for concrete structures, and in distortions, for metal constructions. These singularities must be addressed already in the design stage, but also have to be made carefully in the construction phase.

Alteration or changes in the construction schedule

A change in the construction sequence, due to acceleration of the construction schedule may lead to a construction failure subsequently resulting in expensive delays and reconstruction.

Lack of integration among stakeholders

The complexity of the site and construction management involves coordinating workmanships that deal with different phases of construction: for instance, the realization of load bearing systems and the assembly of other building subsystems (envelope, internal systems, mechanical/plumbing/electrical systems). In this perspective, the integration of the different stakeholders is of utmost importance to reach the expected building quality.

3.2.4 Common construction errors in the MEP-HVAC systems

Because buildings have gotten better insulation over the past decades, installations have become crucial in realizing and maintaining a good indoor climate.

Unfortunately, many mistakes are made with these installations, especially the more complicated systems that make use of sustainable technologies, such as Aquifer Thermal Energy Storage (ATES) or heat pumps. Often times, the systems are not connected the right way, or used in another manner than is appropriate, which in the least leads to excess energy use. In the worst-case scenario, the indoor climate will suffer as well, but the difficulty is that often the indoor climate is still ‘okay’, and the defects remain undiscovered for a long time.

Errors can occur in both the design and construction phase. Three categories can be distinguished in both of these spheres: actual inexcusable faults, sub-optimal use of installations, and mismatch between the different components of a system. An example of a fault is to connect a component the wrong way around. This is inexcusable and the system will

not work. Sub-optimal use is to use a component in conditions other than it was designed for. This leads to excess energy use, but the component still works (otherwise, it should be characterized as a fault). A mismatch occurs at system level, when different components are not (fully) compatible with each other. This leads to either a poor indoor climate, excess energy use, or both.
To discuss some common errors in these categories, examples from heating systems are used. Any part of any heating system can be connected inadequately and result in the system operating poorly. The goal here is not to list all possible faults, but some of the most common errors. The errors originate from the standard solutions for conventional heating systems that do not fit non-conventional heating systems.

Common faults

Heating systems abide by the laws of physics. Even in simple systems like a gas-fired boiler with common radiators, things can go wrong. For example, radiators have to be hung in a specific way; there is an inlet and outlet for the water (not interchangeable) and to facilitate the water flow, the radiators should never be hung perfectly level. However, for the most part these are errors that only inexperienced do-it-yourselfers make, because these systems are so common to the professional mechanic.
However, when the system gets more complex, 'stupid' errors like these can occur. For example, in systems that use a non-typical heat source, such as air or ground temperature, a heat exchanger is required. Usually these are counter-flow heat exchangers: the water circuit of the indoor heating system flows in the other direction than the water in the source circuit, to ensure maximum heat exchange at a high temperature level. If the heat exchanger is connected the wrong way around, the heat exchanger functions as a parallel-flow heat exchanger and the temperature level will drop. As a result, the system does not deliver the required heating.
Faults like this can also occur in the design stage. For example, a heating system that uses a heat pump usually operates at relatively low temperatures (45°C). To be able to have enough heating power (that ensures that a room heats up within an acceptable amount of time), this means that the heat distribution system (such as the radiator, or underfloor heating ducts) has to be a dimension bigger than is the case with higher temperatures.
Faults like these are not acceptable; when designer and mechanic are both skilled, these errors should simply not occur. There is nevertheless a subtle dynamic in the building process that leads to faults. Installations and ducts take up space; unfortunately this is sometimes neglected in the design phase. This can lead to a situation where it is impossible to execute the design, because the necessary space is simply not available. The mechanics will have to think of 'creative' solutions on-site, that mostlylead (inevitably) to errors. However, it would be unfair to attribute this error to the mechanics; when the design cannot be implemented, they try their best to make it work. However, they can never do the appropriate calculations on-site. This dynamic is one of the most common causes for errors; the appropriate calculations have been made, and the mechanics are skilful, however they have to make decisions without proper information. If installation components would be included in BIM, this kind of errors could be minimized.

Common sub-optimality issues

Most errors with MEP/HVAC systems are not as bad as these actual faults however they do lead to sub-optimal operation. Especially MEP/HVAC systems that make use of sustainable energy sources are complex systems that need a control system to operate. For example, when a heat pump is used for heating, it is mostly combined in a hydraulic circuit with an auxiliary heater. This is because heat pumps are not as flexible as conventional gas heaters; they are slow to start and cannot be turned on and off constantly.

This requires a different way of thinking. With a conventional heating system, the only questions were whether the heater had enough power and whether there were enough radiators in each room. Sustainable energy systems, however, are usually carefully designed to exactly meet the heating demand; if the system has too much power, it can provide less, not more, of the heating demand because of the flexibility issues mentioned above. And, because of the number of components, it is essential to properly tune the control system.

For example, when a heat pump has too much power, the temperature fall over the distribution system will be too small. This means in the next round, the thermodynamic cycle will have to operate on a higher temperature level to keep going, which is unfavorable for efficiency. Of course the return flow will have an even higher temperature when it returns. In the end, the heat pump has to shut down because of the high temperature levels; this is simply because the heat pump delivers too much heating power. Because of this, the auxiliary heater is used much more than would have been necessary if the heat pump had been of smaller capacity.

Problems with the control system can lead to both excess energy use and a bad indoor climate. They can occur both because of the physical circuitry, but also because of the used control parameters. For example, in the case of an auxiliary heater, this should always hydraulically be connected *after* the flow passes the primary heater (such as a heat pump), not before. This would lead to the same situation as described above: the temperature level is too high for the heat pump and the control system will shut it down. As to control parameters, a heating system can be controlled using the flow or the temperature level (as power is defined by flow time’s temperature). Conventional systems have always been controlled using the temperature level, keeping a constant flow through the system. However, using a heat pump means that the temperature levels are part of the design; they affect the efficiency of the heat pump. To control the amount of heat delivered, the control system should therefore change the flow into the heat exchanger, to preserve the temperature levels. When this is not done, again the heat exchanger will shut down more often than necessary. In case of a heating system without an auxiliary heater, this means the indoor climate will suffer.

An example of bad indoor climate due to an inadequately tuned control system can also be found in ventilation. Perceived temperature and comfort depends on temperature levels, but also temperature gradients and air flow in a room (draft). If the control system does not respect appropriate minimum and maximum levels for these parameters, the indoor climate can get uncomfortable. For example, when it is 30°C outside, it can be very uncomfortable when the air handling unit blows air of 20°C into the room, especially when it does so with high flow, because the control system is tuned to bring the temperature down as quickly as possible.

Most of these sub-optimality issues can fortunately be repaired after the fact, by tuning the control system and/or replacing one or more components of the circuitry. For example, when the control system needs to be able to control the flow, the pumps in the circuitry must allow for this; they need to be flow regulated pumps.

Common mismatches

Mismatches are very similar to sub-optimal use errors, but a mismatch occurs at system level. The last example given in the previous paragraph relates to this kind of mismatch: when the control system needs to be able to regulate the flow, the pumps must allow for this. The components in the whole system need to match.

Another example of mismatch can be found in Aquifer Thermal Energy Storage systems. The idea of these systems is that they can deliver both heating and cooling. These systems are always fitted with heat exchangers and heat pumps. In winter, the warmth from the aquifer is transferred to a fluid circuit that drives the heat pump. The aquifer flow is cooled down by the heat pump and this cold is stored in the aquifer for use in summer. The heat pump can deliver heat at 45°C using the energy in the aquifer. In summer, the process is reversed. However, cooling should be done without using the heat pump for efficiency reasons. This is perfectly possible; temperature levels in the cold aquifer are usually around 10-12°C. However, conventional cooling systems use a temperature level around 6°C.

This means that, when the air-handling unit (AHU) is not designed for high-temperature cooling, it cannot deliver the cooling demand using the 10-12°C flow from the aquifer. The control system will turn on the heat pump in reverse mode, to cool down the flow to 6°C. This is necessary both because of the cooling demand, but also because of the required injection temperature level: when the aquifer cannot deliver the cooling because of a mismatch in temperature levels, the aquifer flow will not be properly warmed up and the temperature level will be too low for injection into the warm aquifer.

This situation, where the temperature levels do not match, leads to both excess energy use and poor indoor climate. The cooling demand cannot be met adequately, and because the heat pump is used for cooling, the energy efficiency of the ATES is much lower than it could be. The same applies when the heating system is not designed for low-temperature heating. This means the heating demand cannot be met with the low temperature levels delivered by the heat pump, which means that the auxiliary heating unit (usually gas-fired) is used to crank up the temperature level at all times.

It would seem most of these errors happen at the design stage. However, as mentioned in the category ‘faults’, sometimes mechanics have to make adjustments to the design because there is no space for it. As conventional systems operate on different temperature levels, the solutions they may come up with to solve the space issue might lead to this kind of mismatch. This is especially true for these low-temperature heating and high-temperature cooling systems, because the heat exchangers and/or delivery units for these systems are physically required to be bigger.

4. Proposed INSITER Key Performance Indicators for energy-efficient buildings

In INSITER we distinguish three types of Key Performance Indicators:

1. **Building Technical Quality** KPIs regarding the performance of the building itself, e.g. Indoor Environmental Quality and Energy Performance;
2. **Management Quality** KPIs regarding project management performance in terms of Budget, Quality, Schedule, Organization, and Information,;
3. **INSITER Tool** KPIs, regarding the efficiency and effectiveness of the INSITER methodology and related tools.

Building technical KPIs

The building technical Key Performance Indicators "say" something about the performance of the building itself, e.g. air leakage, sound insulation, regarding building quality as well as energy performance.

These KPIs are relevant for the decision making whether the building fulfills its technical requirements, and if not, to what extent an omission leads to decreased energy performance or cost and time increase due to necessary rework.

The measurements of these KPIs are strongly dependent on the hardware monitoring tools as part of WP2, BIM implementation as part of WP4 and the calculation & simulation tools as part of WP3.

Management quality KPIs

In the construction report of the KPI working group of the Minister of Construction of the UK under the headline of ´Rethinking Construction´ a discussion about the set up of ambitious improvement targets was raised in order to enhance the common quality of construction efforts. What is the reference?

The idea was to challenge the building industry to measure its performance over a range of activities and to meet with a set of ambitious improvement targets. From the perspective of the client the projects should be delivered: on time, within budget, free from defects, efficiently, right first time, safely and by profitable companies. The measurements of these KPIs are strongly dependent on the software monitoring tools and BIM, developed in WP3 and WP4 respectively.

INSITER Tool KPIs

The INSITER Tool KPIs "say" something about the effectiveness and efficiency of the INSITER tool and methodology through supporting self-inspection & self-instruction processes. These KPIs show whether INSITER methodology adds value in comparison to the 'traditional' instruction and inspection processes. Based on these Indicators the stakeholders can decide on the approach they want to adopt for their project: the traditional way or the INSITER way. The measurements and validation of these KPIs are strongly dependent on the project and building type, implemented inspection instruments, training and cultural issues related to involved companies. Some of these elements will be developed as part of WP5 and WP6.

4.1 Total overview of KPIs, measurement parameters and technical references

The chapter defines in two different tables the main aspects related to the KPIs presenting a preliminary overview of the main measurements instruments and parameters. The tables will be update in the next month with new input from other WPs.

Topic	Definition
KPI-Level	The KPI-Level describes the thematic area the KPI is aiming for. In INSITER project there are three agreed KPI-Levels: 1. Building 2. Project-Management 3. INSITERS´s effectiveness
KPI	A Key Performance Indicator is a **quantifiable output measure**, **agreed upon beforehand**, that can be used to estimate or compare performance of buildings or (sub)-systems
Measurement aspect	The Measurement Aspect defines a specific issue related to the given KPI
Measurement instrument	The instrument used for the measurements
Parameter	The Parameter is a measured value which serves the Measurement-Aspect

KPI-Level	KPI	Measurement aspects	Sensors / Measurement Instruments	Parameters
Energy Efficiency	Heat transfer	Thermal transmittance	Thermal Camera, Heat Flux Transducer	U Value [W/m^{2}K]
		Transmission Loss	SoundBrush	TL [dB]
		Humidity	3D Laser Scanner	Index of reflectivity L
		Thermal Bridge	Thermal Camera	H_D [W/K]
		Air tightness	Blower-door test, Ultra Sound Device	N50-value [1/h] Airflow [m^3/s]
		Geometric conformity of elements	3D Laser Scanner	Dimension difference [mm]
		Flexibility of joint filling material	Elasticity	[%]
		element positioning	3D Laser Scanner	Dimension difference [mm]
		Ventilation rate	Air flow capture hood	[-]
		Heat recovery system efficiency	-	[%]
	Efficient heat/cold generation	COP values of heatpumps	-	[-]
		Efficiency of boilers	-	[%]
	Efficient heat/cold distribution	Efficiency of system	-	[%]
	Efficient energy use of appliances	Energy label	Photograph	Energy Index
Indoor Environmental Quality-	Thermal comfort	Draught rate		%

		Maximum and minimum air velocity	Air Velocity Meter	m/s
		Vertical air termperature	Thermometer	Temperature [c]
		Warm and cool floors	Thermometer	Temperature [c]
		Relative Humidity	RV meter	%
		Radiant asymmetry	Thermometer	k
	Visual comfort	Luminance	Lux meter	Lux
		Color temperature	Thermometer	K
		UGR value	Calculation based on illuminance	NA
		Daylight factor	Calculation based on illuminance	NA
		LTA (Light Transmission Aggregometry)	Calculation based on illuminance	NA
	Acoustics	Sound intensity field	SoundBrush	Sound intensity level [dB]
		Sound pressure level distribution	MEMS microphone array for Beamforming	Sound pressure level [dB]
	Indoor air quality	CO^2	CO^2 meter	Parts per Million [ppm]
		Emission from appliances and interior materials	VOC meter	Ppm
		Air supply rates	Air Velocity Meter	M3/hour per person

4.2 Explanation of Building Performance KPIs

Energy efficient Building (EeB) oriented KPIs are related directly to the quality issues at available or use discussion and the quality issues at the end of defect rectification period. The most important quality field in the EeB focus is the energy consumption e.g. actual and forecasted in kWh/(m² x a).

INSITER aims to eliminate the gaps in quality and energy-performance between design and realization. For that purpose, “quality” is defined as “Indoor Environmental Quality”.

Other types of building quality, such as structural integrity or visual quality of buildings are considered out of scope. “Energy efficiency” is a ratio between an output of performance, service, goods or energy, and an input of energy. In other words using energy in an efficient way to provide healthy and comfortable buildings

For **Indoor Environmental Quality** the following main KPIs are taken into account:

- Thermal comfort;
- Visual comfort;
- Acoustics;
- Air quality.

The **Energy Efficiency** related KPIs focus on:

- Heat transfer of the building envelope;
- Efficiency of heat/cold generation;
- Efficiency of heat/cold distribution.

To prevent performance loss many measurement aspects have to be controlled that can be grouped under the main headings of “Indoor Environmental Quality” and “Energy Efficiency”. These measurement aspects will be further elaborated below. In chapter 4 the construction errors related to these measurement aspects are discussed and in chapter 2 the existing protocols and norms to inspect are presented.

4.2.1 Indoor Environmental Quality KPIs

Thermal comfort [NEN-EN-ISO 7730:2005]

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment.

Dissatisfaction can be caused by warm or cool discomfort of the body as a whole, as expressed by the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD), or by an unwanted cooling (or heating) of one particular part of the body. Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody. There will always be a percentage of unsatisfied occupants. But it is possible to specify environments predicted to be acceptable by a certain percentage of the occupants. In buildings, general and local thermal comfort could be distinguished.

General thermal comfort could be evaluated based on the following aspects/measures:

- **Predicted Percentage Dissatisfied** (PPD) which is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm.
- **Predicted Mean Vote** (PMV) which is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale, based on the heat balance of the human body.
- **Operative Temperature** which is uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment.

Local thermal comfort could be evaluated based on the following aspects/measures:

- **Draught** which is the discomfort due to draught may be expressed as the percentage of people predicted to be bothered by draught.
- **Vertical air temperature** difference which measures the discomfort caused due to temperature differences between head and ankles.
- **Warm and cool floors** which may affect comfort of occupants owing to thermal sensation of their feet.
- **Radiant asymmetry** which can also cause discomfort for people by warm ceilings or cool walls (windows).

Visual comfort [NEN-EN 12464-2:2014]

The function of lighting in a building can be subdivided in three domains: Health and safety, visual performance, and aesthetics. The lighting of an area should be adequate to ensure that people can live safely, and it should not in itself be a health hazard. Assessment of the visual environment can provide information as whether or not these criteria are met.

Luminous environment

For good lighting practice, it is essential that, in addition to the required illuminance, other qualitative and quantitative needs are satisfied.

- Lighting requirements are determined by the satisfaction of three basic human needs:
  - Visual comfort, where the workers have a feeling of well-being; in an indirect way also contributing to a high productivity level;
  - Visual performance, where the workers are able to perform their visual tasks, even under difficult circumstances and during longer periods;
  - Safety, where building users have enough light to carry out their activities safely.

Main parameters determining the luminous environment are:

- ***Luminance distribution***, which controls the adaptation level of the eyes, which affects task visibility. A well balanced luminance distribution is needed to increase:
  - Visual acuity (sharpness of vision);
  - Contrast sensitivity (discrimination of small relative luminance differences);
  - Efficiency of the ocular functions (such as accommodation, convergence, pupillary contraction, eye movements).
- ***Illuminance*** and its distribution on the task area and the surrounding area have a great impact on how quickly, safely and comfortably a person perceives and carries out the visual task. It includes the following aspects:
  - Illuminance on the task area;
  - Illuminance of surroundings;
  - Illuminance grid;
  - Uniformity and diversity.
- ***Glare***, is the sensation produced by bright areas within the field of vision and may be experienced either as discomfort glare or disability glare. Glare caused by reflections in specular surfaces is usually known as veiling reflections or reflected glare.
- ***Obtrusive light*** also known as light pollution, which can present physiological and ecological problems to surroundings and people.
- ***Directional lighting*** may be used to highlight objects, reveal texture and improve the appearance of people. This is described by the term “modelling”. Directional lighting of a visual task may also affect its visibility.
- ***Colour aspects*** The colour qualities of a near-white lamp are characterized by two attributes:
  - The colour appearance of the lamp itself;
  - Its colour rendering capabilities, which affect the colour appearance of objects and persons illuminated by the lamp.
- ***Flicker and stroboscopic effects*** cause distraction and may give rise to physiological effects such as headaches. Stroboscopic effects can lead to dangerous situations by changing the perceived motion of rotating or reciprocating machinery. Lighting systems should be designed to avoid flicker and stroboscopic effects.
- ***Maintenance factor***: The lighting scheme should be designed with a maintenance factor calculated for the selected lighting equipment, space environment and specified maintenance schedule, as defined in CIE 154:2003.

Acoustic comfort *[Steskens & Marcel Loomans, D1.3 Performance Indicators for Health and Comfort, PERFECTION, Brussels]*

Noise effects resulting from outside and inside sources may have an adverse influence on occupants' comfort as well as on their intellectual and physical performance. The typical indicator of acoustic comfort is the level of acoustic pressure. Moreover, acoustic comfort can also be assessed on the basis of users' satisfaction.

- Acoustic performance

The overall objective of the performance indicators regarding the acoustic comfort in a room is to provide acoustic conditions in a building that facilitate clear communication of speech between the users of the building. The following indicators have influence on acoustic performance:

- Indoor ambient noise levels;
- Airborne sound insulation between spaces;
- Airborne sound insulation between corridors or stairwells and other spaces;
- Impact sound insulation;
- Reverberation;
- Speech intelligibility;

- Indoor ambient noise levels in unoccupied spaces

The indoor ambient noise level includes noise contributions from:

- **External sources outside** the building (including, but not limited to, noise from road, rail and air traffic, industrial and commercial premises)
- **Building services** (e.g. ventilation system, plant, etc). If a room is naturally ventilated, the ventilators or windows should be assumed to be open as required to provide adequate ventilation. If a room is mechanically ventilated, the plant should be assumed to be running at its maximum operating duty.

- Airborne sound insulation between spaces

The objective is to attenuate airborne sound transmitted between spaces through walls and floors. The required minimum airborne sound insulation values between rooms are generally defined by the activity noise in the source room and the noise tolerance in the receiving room.

- Impact sound insulation of floors

The impact sound (e.g. footsteps) transmitted into spaces via the floor is limited by the recommended maximum weighted standardized impact sound pressure level for receiving rooms of different types and uses.

- Reverberation

The reverberation time of a room used to be regarded as the predominant indicator of its acoustic properties. The reverberation time of a room is defined as the time required for the sound pressure level to decrease by 60 dB, at a rate of decay given by the least-squares regression of the measured decay curve from a level of 5 dB below the initial level to 35 dB below the initial level.

- Speech Intelligibility

Within a building, clear communication of speech between the users of the building should be provided. Large spaces, such as open plan spaces, require extra specification, as these may be more complex acoustic spaces. The main issue is that the noise from different groups of people functioning independently in the space may significantly increase the background noise level, and thus decrease speech intelligibility (STI-value).

Air quality [NEN-EN 13779]

The most important design assumptions with respect to the indoor air quality are information about the human occupancy, whether smoking is allowed or not, and emissions from sources other than human metabolism and smoking. It should also be taken into account that air quality is likely to be perceived more negatively as temperature and humidity increase.

Emissions from sources other than human metabolism and smoking shall be specified as clearly as possible. If no further emissions are taken into consideration, this shall be noted in design documentation.

- Supply airflow rates: The outdoor air rate could be determined using the following criteria:
  - human occupancy with or without smoking
  - other known emissions
  - heating or cooling load that shall be dissipated by ventilation.

In order to prevent uncontrolled loss of supply air, the ductwork shall be airtight enough. Methods to estimate the impact of air leakages in ducts and air handling units are described in EN 15242.

- Extract airflow rates: In a balanced mechanical ventilation system with supply and extract air the extract airflow rate is given by the supply airflow rate and the pressure conditions needed.
- Other emissions: emissions from interior materials and appliances have influence on the indoor air quality.
- CO2 concentrations: high concentration of CO2 in buildings is an indicator of indoor air quality. Allowed CO2 percentages depend on building classification and outside CO2 concentrations.

4.2.2 Energy Efficiency related KPIs

Heat transfer

Heat transfer of buildings can occur in three ways; by convection, conduction or radiation through the building envelope. To reduce these heat losses, several parameters have to be taken into account, especially regarding convection (ventilation) and conduction (transmission) of the building envelope (NEN 7120).

Convection

Regarding convection, it is important that no air infiltrates through the building envelope, which can be prevented if the building is sufficiently airtight. In this case, special attention needs to be paid to the junctions between the prefabricated elements. If the joints are too wide, air leakage will occur, which negatively influences the energy performance. To keep the junctions as tight as possible, the prefabricated elements have to have the correct dimensions and have to be positioned in the right place. Especially in the renovation sector a basic survey related to the existing structure, its reliability and the dimension of the existing building and the points of junction with the prefab elements are very important. Moreover, the filling of the joints needs to be able to fill the whole with of the remaining open space between the building elements.

European countries include in their regulations either required or recommended minimum air tightness levels with or without mandatory testing. There are several countries (e.g., United Kingdom, Germany, France, Portugal, Denmark, Ireland) where, by regulation, air tightness testing is mandatory for certain building types or in the case of specific programs.

Apart from infiltration, air also enters the building through 'regular' ventilation systems that are necessary to guarantee a comfortable and healthy indoor environment. Ventilation occurs by means of natural ventilation or forced ventilation. The self-inspection checks for natural ventilation strongly depend on the ventilation system that is designed. For example, if the design includes only openable windows or mechanical air extraction (without heat recovery) there is no self-inspection possible during construction. However, if it uses CO^2 guided ventilation valves, then the characteristics and set points of the sensors should be inspected and verified with the design requirements.

In case of forced ventilation with heat recovery, the specifications of the heat recovery system that is installed should meet the requirements of the design.

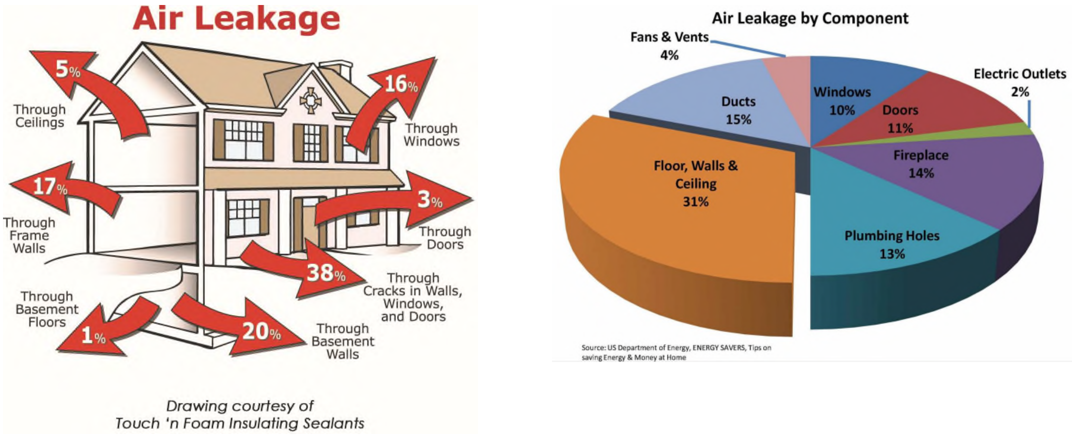


Fig. 16 – Air leakage representation (please note that the percentage estimated in the graphic depends by the methods adopted and by the Country)

Conduction

Next to transfer through convection, heat is also transferred via conductivity of the materials of the building envelope. To prevent heat transfer through conduction, materials are applied to the building envelopes that have low thermal conductivity.

The insulating capacity of materials is represented by the R-value. A high R-value implies high insulation. On the contrary, thermal capacities of glass are represented by U-values, where a low U-value represents the high insulation capacity.

It is important that the insulating materials form a closed shell around the building without discontinuities. These discontinuities occur when insulation material suffers from water infiltration or humidity, or when insulation panels do not fit well one to another or are badly positioned. In addition, thermal bridges arise when a high conductive material links the outside of the building envelope with the inside. Self-inspection during construction should focus on the prevention of these discontinuities.

Radiation

Heat transfer through thermal radiation is prevented by applying low-emissivity building materials. Examples are window glass manufactured with metal-oxide coatings as well as reflective thermal insulations and other forms of radiant thermal barriers. It is important to check on-site if the specs of the materials match with the design characteristics.

Efficient heat/cold generation

The generation of heat or cold is necessary to adjust the indoor climate to the desired set points and comfort levels of the building occupants. Nowadays, in buildings with good thermal insulation of the building envelope the generation of cold is more important than heat, because the internal heat load of lighting, computers etc. is considerable. Regarding heat or cold generation it is important that prior to installation in the building, the specs of the boilers and cooling machines are checked on site: “are we placing the product that has been used in the calculations”?

Efficient heat/cold distribution

Once the heat or cold is generated, usually in a central place in the building, it has to be distributed to the rooms and areas where it is needed. In this process, the dimensions of the ducts and pipes need to meet the requirements of the design, to prevent capacity losses or too high air speed levels.

The assembly of the elements of the distribution system needs to be carried out correctly as well, and this is where self-inspection and self-instruction are much needed to prevent errors, which can occur by incorrect installation of duct insulation material which could lead to condensation, or even installing pumps in the wrong pipe or in the wrong direction.

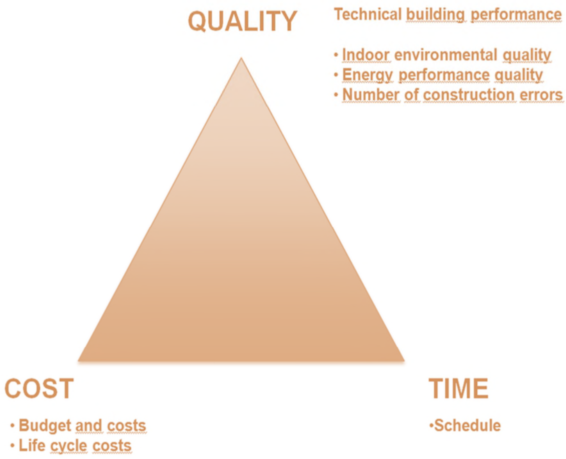
4.3 Explanation of Project Management KPIs

As the attitude towards EeB has been changed the attitude to the KPI groups deducted from the above mentioned overview is still the same: time, cost, quality, client satisfaction, client changes, business performance and health and safety are the seven identified KPI groups or quality fields. INSITER KPIs are related directly to the first three quality fields of time, cost and quality issues assigned to energy-efficient buildings.

The self-inspection and the self-instruction promoted by the INSITER tools aim to provide an outstanding raise of the EeB performance quality at new building, renovation and maintenance level promoting new self-inspection and self-instruction processes at the same time.

The defects or construction errors are embedded as an indicator at any level of the most important three above mentioned quality fields. The time defect relationship is focusing on the time to rectify defects, the cost defects relationship is focusing on the cost of rectifying defects and the core of the INSITER oriented defect analysis and building process improvement is embedded in the quality discussion. The survey of defects and their assignment to the quality fields is focusing on different improvement levels: Time oriented defect prevention is shortening the building time and enhances the predictability of time for construction.

These issues will be discussed in chapter 4.3 Explanation of project management KPIs. The measured values –KPIs- are related to consumed time / extra time for interventional actions. The cost oriented defect survey is related to the extra costs created by defect rectifying actions. The measured value is money.



Project management issues are embedded in all seven KPI groups: time, cost, quality, client satisfaction, change orders, business performance and health and safety. The indicators for time steering are in general time for construction forecasted and actual during design and construction phase and especially related to time to rectify defects. The influence on the predictability of the time based on client change orders is as crucial as the influence of an unexpected leader change order. The influence is measured in forecasted and consumed time.

The second group is about costs and predictability and steering of costs for the construction and in use. The influence is measured in budget forecasted and consumed. The financial steering of a site is a part of the project management but not included in the INSITER scope. Nevertheless the cost of rectifying defects survey is included in the INSITER development and quality assuring process in order to analyse a threshold for a correction budget or a target for a process improvement e.g. if the EeB impact is of minor importance.

The quality definition is related to the lack of defects and the avoidance strategy is promoting the assured quality. In terms of project management issues the efforts made in order to get rid of defects –intervention activities in the regular project management process- have to be balanced against the demand of defect rectification. Appropriate KPIs are time consumption related to additional project steering means in order to rectify defects or to document the lower defect impact.

The regular common project management benchmarking measures are: Return on investment, productivity, cost of quality, cost of performance, schedule performance, customer satisfaction, cycle time, requirement performance, employee satisfaction and alignment to strategic business goals. Related to the INSITER approach these criteria developed by the production industry can be translated to another level. Return on investment could be related directly to the INSITER tool as mentioned below in chapter 4.4.

The investment in hardware and training on the tool has to be balanced against the cost savings for the steering effort on defect prevention and remaining defect rectification. The raise of productivity KPI is measured as the difference between total regular project spending and total spending based on the INSITER process and tool application. The KPI can be calculated on actual total costs basis. An alternative is the cost simulation based on regular cost assumptions.

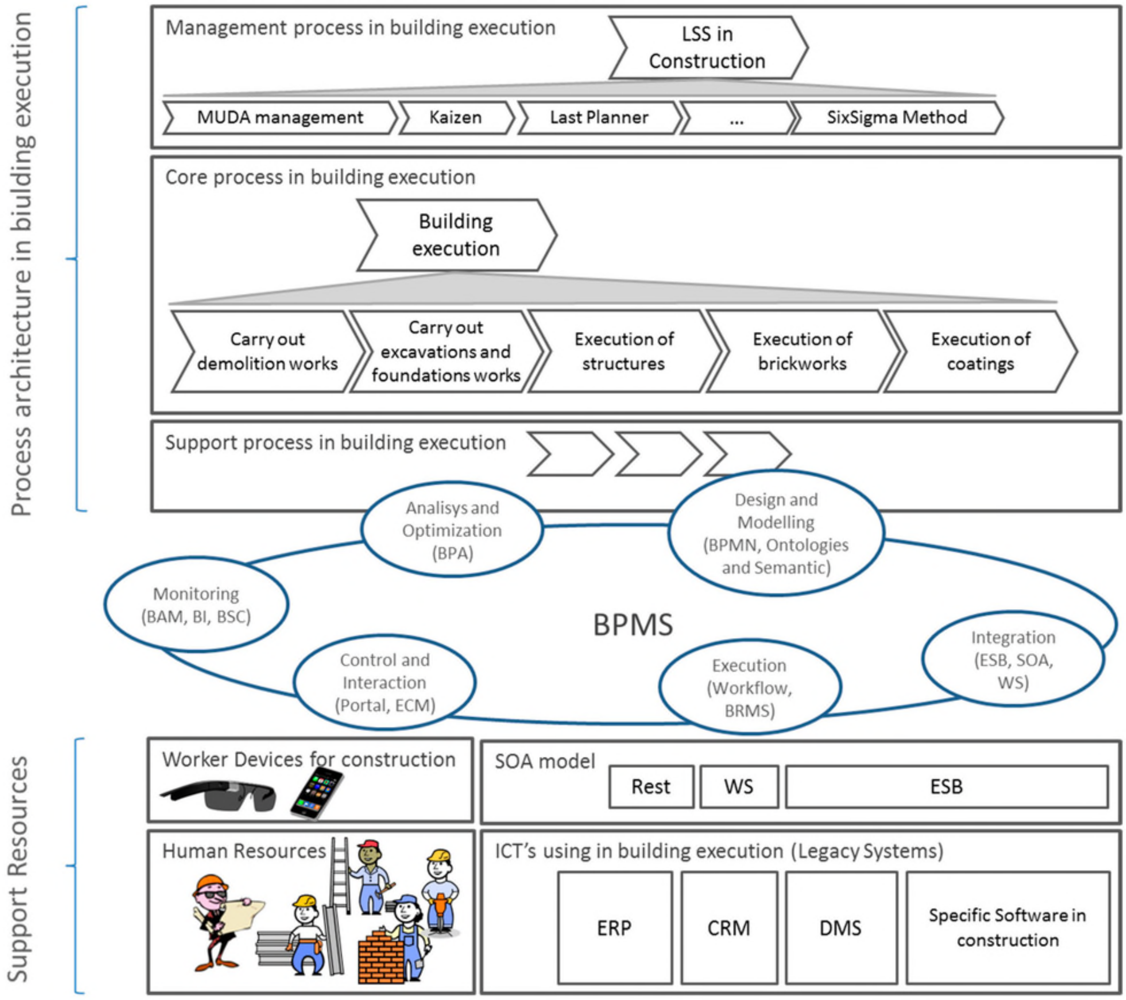


Fig. 17 – Diagram of the building process management

The cost of quality KPI calculation is more complicated as the building industry driven by SMEs is not providing exact data of these costs that arise in the commissioning phase as extra man-hours if defects have to be tackled.

The INSITER KPI should try to recalculate on basis of the calculation methods of construction companies – in experts' literature it is mentioned that up to 30 % of the calculation of a unit price is devoted to defect fixing and doing the work twice- the difference between regular and the INSITER approach.

GROUP	INDICATORS
Time	- Time for construction - Time predictability – design - Time predictability – construction - Time predictability - design & construction - Time predictability - construction (client change orders) - Time predictability - construction (project leader change orders) - Time to rectify defects
Cost	- Cost for construction - Cost predictability – design - Cost predictability – construction - Cost predictability – design & construction - Cost predictability – construction (client change orders) - Cost predictability – construction (project leader change orders) - Cost of rectifying defects - Cost in use
Quality	- Defects - Quality issues at available for use - Quality issues at End of defect rectification period
Client satisfaction	- Client satisfaction product - standard criteria - Client satisfaction service - standard criteria - Client satisfaction – client-specified criteria
Change orders	- Change orders – client - Change orders – project manager
Business performance	- Profitability (company) - Productivity (company) - Return on capital employed (company) - Return on value added (company) - Interest cover - Return on investment (client) - Profit predictability (project) - Ratio of value added (company) - Repeat business (company) - Outstanding money (project) - Time taken to reach final account (project)
Health and safety	- Reportable accidents (inc fatalities) - Reportable accidents (non-fatal) - Lost time accidents - Fatalities

Fig. 18 – Project management indicators

4.4 Explanation of INSITER's Effectiveness KPIs

There is a difference between the above-mentioned KPIs and the INSITER associated innovative quality control assurance process related to effectiveness KPIs. The KPIs and related parameters have to be measured following different technical demands concerning to quality fields. The effectiveness of the INSITER tool will be validated at 3 different levels:

1) At the laboratory;
2) In the factory and;
3) In the field. These KPIs –used in WP5 validation activities- are not directly related to the core of the technical measurements, e.g. a U-value is or is not in line with the technical demand and missing or fulfilling the threshold but with the existence and the number of construction errors. The benchmark is the total expected quality performance level.

One objective is to reduce the total number of errors as much as possible at the first level of the quality check and to eliminate the construction errors that cause the crucial impact on the regular KPIs in the quality fields related to EeB. The target is a reduction of 80 to 90% of the total amount of relevant construction errors and to match with the shortlist of the construction errors causing the most critical effects on the total building quality (elaborated in the next chapter).

Considering the appropriateness of the shortlist there are additional, not just on the total or relative reduction or avoidance of defects related INSITER effectiveness targets and KPIs:

- The ***user friendliness*** of the INSITER tool has to be proven by the KPI of a an enhanced learning curve effectiveness in relationship to regularly applied quality assuring means i.e. the time consumed for training and construction error rectifying. As one of the main problems on site is the lack of qualified workers there is a need to assure the quality on site by providing an easy to handle and to use the tool in order to prevent the construction process errors causing problems on site. The calculation of the INSITER advantage KPI will be done by comparing the opportunity costs for defect rectifying as usual and the INISTER tool steered site oriented costs for defect rectifying and the share of the training demand for the application of the tool.
- The ***investment costs*** for the application of the tool taking into account the sustainable use have to be balanced against the total savings created by the INSITER quality assurance process. However, the decision for the dashboard containing and providing smart tool is not made already. It seems possible that the INSITER tool will be presented as a centralised software solution using a smart phone, a handheld or other easy to handle well introduced hardware tools. In that case it might be obvious that the royalty based cost for the use of the tool have to be related to the enhanced quality of work. This balance will be calculated as another KPI for the INSITER effectiveness.
- As the hardware is foreseen as a robust component a long life time is expected for the application. However, the tools should be ***robust*** enough for frequent use on the construction site
- The defect removal rate shows the efficiency of the defect analysis and the defect rectification. There are two aspects to be measured as KPIs: ***Total number of defects*** with high impact that have to be removed and ***qualification of defects*** with lower impact that can be tolerated.
- Another INSITER effectiveness KPI is related to the European level of the approach. The ***replicability*** should be high so that it can be used throughout Europe for all types of buildings. As in WP 5 it is foreseen to use scenario mapping in order to proof the transferability of the application of the tool in terms of adjustability to national, regional, local or even geo cluster needs the validation of this goal will be measured by the number of countries and regions that might use the INSITER tool after individualising the calculation basics to their individual use.

5. Innovative INSITER protocols to prevent and detect errors at critical areas for EeB

It is important to define a building quality framework to answer four essential questions:

1) What the inspection checklists should be;

2) What quality inspection procedure should be employed;

3) Which kind of technologies/tools are appropriate;

4) How the inspection data should be stored and delivered.

[M.-K. Kim et al. / Automation in Construction 49 (2015) 225–238]

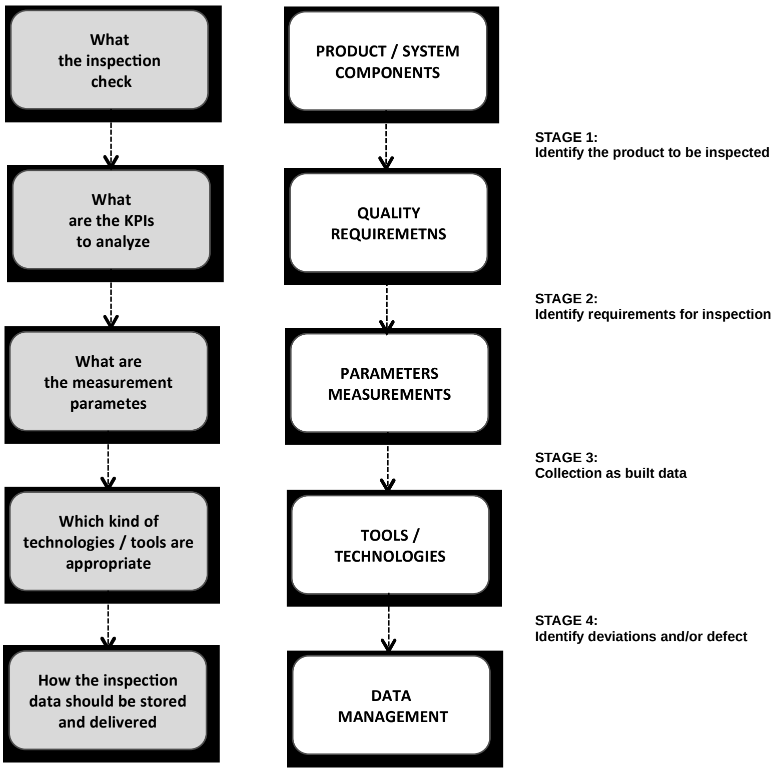


Fig. 19 - On-site inspection framework process.

With a list of all the quality requirements for a specific product, the user can perform guided measurements and assess whether any of the requirements were violated in each task of the process with specific tools and technologies.
Using these different reality capture technologies as-built data can then be collected. Once the as-built data is collected, existing tools can interpret the collected data and compare it to the design information and identify deviations between the design and the as-built data.

The list of identified deviations can then be evaluated by identifying the specifications applicable to deviating products and comparing the requirements imposed by these specifications to the deviations found (next D1.4 and D1.6). If a deviation violates a requirement imposed by a specification, it constitutes a defect.

As mentioned, in the INSITER Description of Action, the research will develop an eight step self-inspection methodology in construction and refurbishment.

The eight defined steps are:

1. Mapping actual technical conditions of the site and building and performing economic valuation of the property and land; capture the requirements and compare them to as-is situation;
2. Self-inspection at procurement, production and delivery of prefab components;
3. Modelling of the [existing] building, site and surroundings in Building Information Model (BIM);
4. Generating and deploying BIM-based Augmented Reality (AR) for self-instruction and self-inspection;
5. Virtual validation of quality and performance by BIM Model Checking and Clash Detection; as well as value and process optimisation by Virtual Reality simulation;
6. Self-inspection and self-instruction during preparation of construction site and logistics;
7. Self-inspection and self-instruction during construction / refurbishment / maintenance process;
8. Self-inspection and self-instruction during pre-commissioning, commissioning and project delivery.

In the *Fig.20* the eight steps are connected in a logic sequence.

At the right side of this figure we see the main questions to be answered for each step:

- **When:** During Refurbishment, Maintenance or New Build Construction
- **Who:** Who are the Key Persons involved?
- **What:** What kind of prefab components and what are the most important KPIs and measurements?
- **What is the aim:** Preventing / detecting main errors, risks, building performance, installation performance, quality or process improvement.
- **How:** What are the measurement tools (hardware and software) or how can augmented reality support?
- **Where:** on site, off site (e.g. factory) or virtual
- **Outcomes:** What kind of outcome do we need and what are we going to do with it?
- **References:** norms, standards, guidelines to follow in each specific test to evaluate the construction error level.

In these terms the Deliverable 1.1 presents the main information to answer of above questions mentioned.

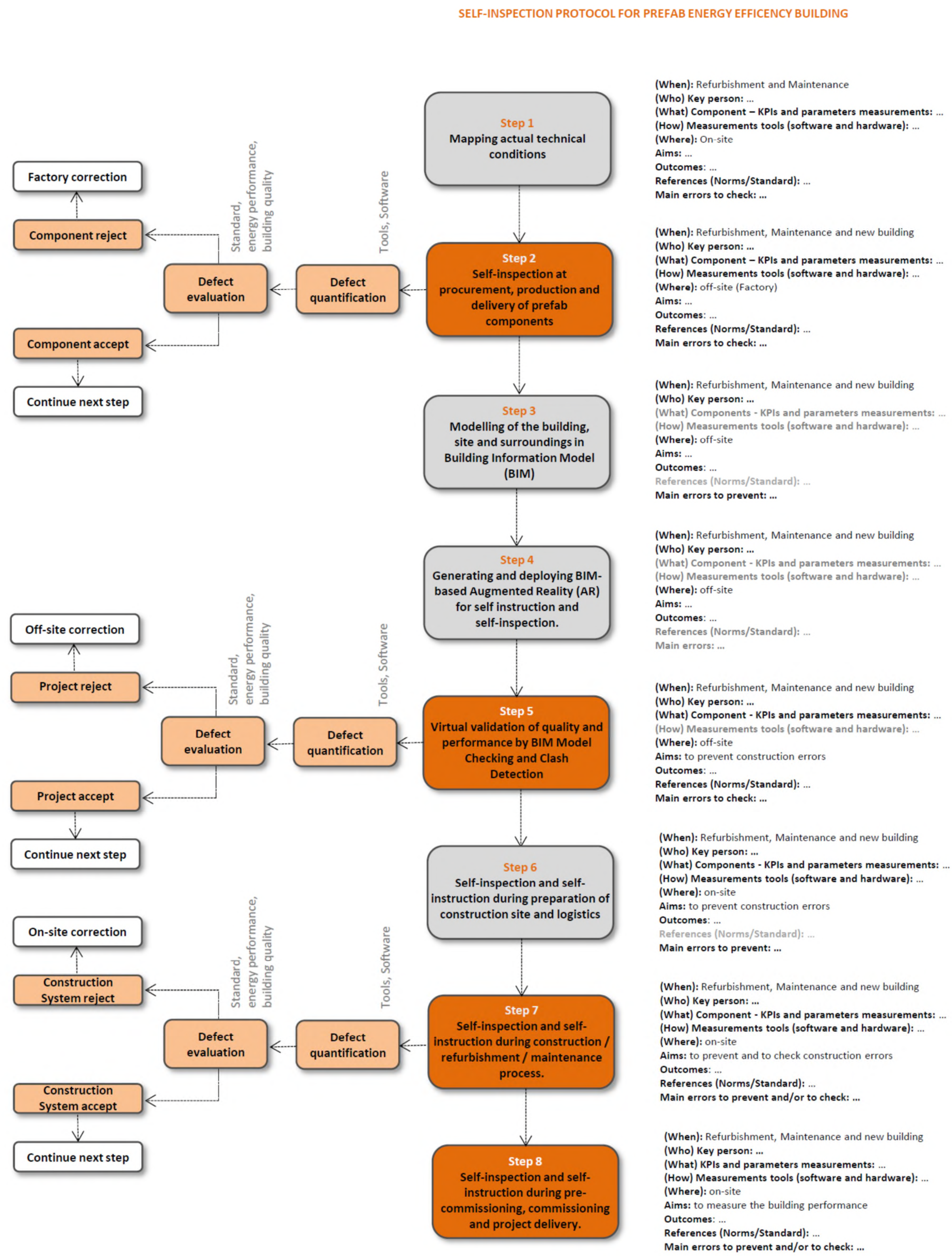


Fig. 20 – Eight steps of innovative INSITER self-inspection methodology

Step	Activity	New construction	Major refurbishment	Planned / key maintenance
1	**Mapping existing building or building parts/systems**	N/A except for building site; starting point is design	Mapping / assessment of existing building; outcomes integrated in 'refurbishment design'	Assessment of existing parts/ systems (e.g. roof, HVAC); outcomes integrated in 'maintenance action plan'
2	**Verifying design and prefab components**	Verifying construction / refurbishment / maintenance plan; verifying the specs of selected prefab components according to design / maintenance solutions		
3	**BIM creation**	BIM design model	BIM models of existing and refurbished building	BIM models of the building or MEP systems subjected to maintenance
4	**Virtual (BIM) validation**	Clash detection; interfacing BIM with software / AR app		
5	**Creation of self-instruction guidelines**	Step-by-step guidelines for construction / refurbishment / maintenance visualised in 3D based on BIM model(s)		
6	**On-site preparation**	Positioning BIM / integrating building site in BIM; verifying ordered and transported prefab components, on-site logistics, cost and time schedules		
7	**Quality validation during on-site processes**	1. Workers watch step-by-step 3D self-instruction on their mobile devices 2. Workers perform the instructed activities 3. Workers compare their own results against 3D model using AR, and send report to Supervisors 4. Supervisors analyse the results online and give approval or request for repair/rework 5. Supervisors evaluate the process and possible implications (e.g. risks, delays, budget overrun)		
8	**Performance validation of the realised building**	1. Take thermal / acoustic / geometric measurements of the realised building or room 2. Analyse the KPIs, compare actual vs. designed to determine whether or not there is a gap 3. Give feedback to on-going on-site processes and/or to design		

Fig. 21 – INSITER 8 step methodology implemented after Y1

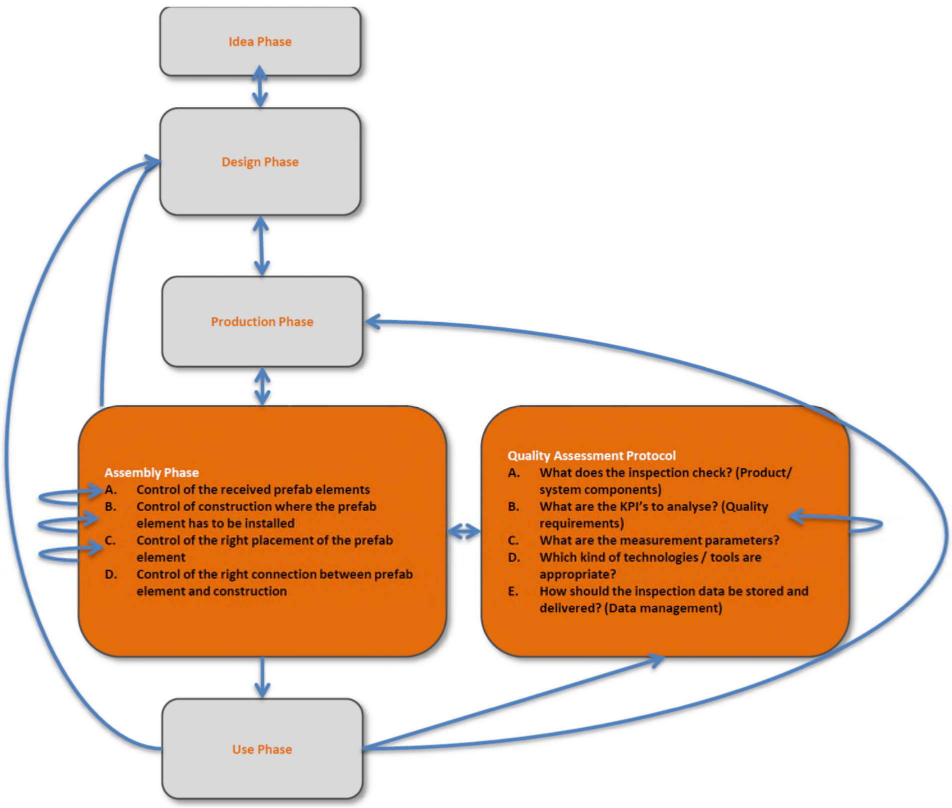


Fig. 22 – INSITER protocol focus on the on-site assembly phase

The Deliverable 1.1 does not presents the final INSITER protocol that will be developed in detail in the next research actions, but proposes a more detail lecture of the INSITER methodology in consideration of analysis proposed regarding the following topics:

- Building process;
- More diffuse construction errors of prefab buildings;
- Energy performance and building quality assurance;
- Inspection methods and tools;
- Standard and norms.

The Eight-step self-inspection methodology is the starting point for more in depth analyses and in the following paragraph we will work this out with the specific focus on the “assembly phase” (on-site).

This protocol has the focus on-site assembly phase. In the on-site assembly phase we see 4 main stages (*Fig. 21*):

a. Control of the received prefab elements;
b. Control of the construction where the element has to be installed;
c. Control of the right placement of the element;
d. Control of the connection between prefab element and construction.

The quality assessment protocol determines for each stage:

- What should be inspected?
- What are the KPI to analyse?
- What are the measurement parameters and threshold values?
- Which technology / tools will be used?
- How should the inspection data be stored and delivered.

D1.4 and D1.6 will describe the measurements more in detail for the building and installation components. This document will provide the basic principles.

The assumption is that all the prefab elements have to be 100% right and that no corrective measurements should be taken on site. Every corrective measurement causes problems and delay in the on-site assembly phase and is seen as an error.

To prevent errors means that we have to learn from every error. The only way is that feedback is given to previous stages or to previous phases.

- Feedback of the errors to a previous stage in the on-site assembly phase;
- Feedback from the on-site assembly phase to transportation, the factory production phase or to the design phase;
- Feedback from the in-use phase to Quality assessment protocol, factory production phase and design phase;
- Feedback within the Quality assessment protocol itself.

5.1 Quality assessment protocol

The quality assessment protocol determines for each stage the right measurements and threshold values. Depending on the prefabricated elements and the risk on errors/defaults. E.g. mounting a prefabricated bathroom needs another quality assessment protocol than the assembly of a prefabricated pitched roof.

Extra attention has to be paid to the most critical areas of each mounting also depending on the type of prefabricated element and the place.The focus of the quality assessment protocol for INSITER purposes should be on:

1. Building Technical Quality (e.g. Indoor Environmental Quality, Energy efficiency)
2. Management Quality KPIs regarding project management performance in terms of Budget and Costs, Organization, Planning, Information, Quality;
3. INSITER Tool KPIs, regarding the effectivity and effectiveness of the INSITER methodology.

The feedback loops are very important for continuous improvement of the quality and preventing errors. Although the focus is on errors, it can also be used for improving the design, production or the assembly of the prefabricated elements and of the design of the building itself. Most important are the workers.

The worker needs to have the knowledge, skills and competences to meet the demands of the quality assessment protocol. The INSITER self-inspection and self-instruction methodology helps the worker to improve continuously.

The worker plays a crucial role in preventing the errors as mentioned in the four stages of the assembly phase, but also in reporting the errors in the right way and giving input for improvement.

The system should facilitate a system of feedback.

- Feedback of the errors to a previous stage in the assembly phase.
  Errors in a previous stage influence the right placement or connection in the next phase. It is important to detect the error as early as possible and to solve it. Not solving the error direct could cause far higher costs in the end.

- Feedback from the on-site assembly phase to the factory production phase or to the design phase.
  Errors in the on-site assembly phase could be caused by errors in the production of the prefabricated element or during the transport phase. A wrong design could also cause errors which reveal during the on-site assembly phase.

- Feedback from the in-use phase to Quality assessment protocol, factory production phase and design phase.
  Errors might reveal during the in-use phase. Feedback of the errors has to be given to the Quality Assessment Protocol (when the error was a consequence of a bad mounting and a bad control on that. Another opportunity is that the Quality Assessment Protocol did not cover the prevention of the error.), to the factory production phase (when the error is caused by a production failure) or to the design phase (when the error is caused by a bad design for the product or a bad design for the building).

5.2 Stages in manufacturing and on-site assembly phase

The chapter presents the main on-site action to reduce the construction errors.

5.2.1 Manufacturing process quality control

Construction Procedures will be drafted for singular activities or for those activities that are highly difficult to carry out.

- They should be drafted by people with extensive experience in the implementation of such activities. To this purpose, the Quality Manager - when appropriate - will address Dragados Technical Directorate.
- Their content must be essentially practical, collecting personal experience that allows anticipating problems that may arise.

Method Statement will be prepared at the discretion of the Quality Manager for activities whose implementation is customary.

- They will describe the measures and operations necessary to execute the activity. The points that may pose greater problems related to quality during the development of the activity will also be highlighted.
- Their main mission is to serve as a roadmap for the implementation of the activity, since it is assumed that the worker has sufficient experience to carry out the work.

Every activity has a specific **Inspection and Testing Plan** (ITP) with their respective register.
The ITP for each activity shows all the elementary operations to be tested when executing it. Such operations are clearly specified in their logical order of execution.

The ITP template follows the rules on standardized form SF-04 GP-2.03, whose content is as follows:

- Description of operation to be controlled;
- Standard or Procedure on which execution is based;
- Type of inspection (visual, surveyal, laboratory, etc.);
- Frequency,
- Person responsible for inspection;
- Whether or not it is a waiting point, i.e., whether it is necessary to wait for approval of the operation before going on with the execution;
- The specifications on which the person responsible for inspection will base in order to accept or not the operation. Where applicable, it will be necessary to include any specific and essential working environment conditions which may be necessary for a correct execution of the activity.

DRAGADOS	PROGRAMA DE PUNTOS DE INSPECCIÓN (P.P.I.)	PLAN 297/100 HOJA 1 VERSIÓN 3 FECHA marzo-14
OBRA:	FACTORÍA DE LAS CABEZAS DE SAN JUAN	CÓDIGO: 297/100
ACTIVIDAD:	FABRICACIÓN DE MÓDULOS	P.P.I. Nº: 1

Nº	OPERACIONES	PROCED. O NORMA	TIPO DE INSPEC.	RESP	FRECUENCIA	ESPECIFICACIONES
1	HORMIGONADO					
HORMIGONADO	Control de la gestión de acopios	EHE 08	VIS	RPROD	100%	Acopio ordenado por material, forma de suministro, fabricante y partida suministrada, en su caso
	Despiece de planos de armaduras diseñadas según proyecto	EHE 08	PLANOS		100%	Planillas corresponden con lo que indica los planos de proyecto.
	Montaje de armaduras mediante soldadura NO RESISTENTE	EHE 08	VIS		100%	Existencia de soldadura entre malla y entrevigado. No se desprende la malla electrosoldada.
	Geometría y solape de las armaduras pasivas, malla electrosoldada (HABITUAL 150.150.5)	EHE 08. Art.69	MET		Cada suministro. 100%	Conjunto de armaduras elaboradas cada jornada coinciden con las de proyecto.150.150.5. / longitud minima solapo 200 mm
	Vertido y puesta de hormigón	EHE 08	VIS		100%	1 jornada /150 m3.Hormigon coincide con especificaciones de proyecto. Vibrado y vertido inf alt 1 mt. Sin juntas frias. HORA SALIDA /HORA VERTIDO INFERIOR 90 MINUTOS
	Curado del hormigon. Desencofrado. Aspecto final.	EHE 08	VIS		100%	150 m2 de superficie de hormigón. Sin coqueras. Aspecto liso apto para colocacion pavimentos
	Recubrimiento hormigon de malla electrosoldadda	EHE 08. Art 37.2.4	MET		Al menos 2 mediciones por suelo.	20 mm en el caso de vida util inf 50 años/ 30 mm en el caso de vida util entre 50 y 100 años
	Aplicación de tratamientos de protección anticorrosion	EAE 2011	LAB		Al menos una visita externa por proyecto	Tratamiento aplicado en una jornada. Control de proteccion anticorrosion, pintura intumescente. Especificacion según proyecto. Al menos 10 medidas ninguna inferior limite.(Medidas habituales 120 micras en proteccion o 600/800 micras intumescente)
	Aplicacion de tratamientos morteros intumescentes	CTE/Proyecto	LAB		Al menos una visita externa por proyecto	Tratamiento aplicado en una jornada. Control de espesor mortero. Sin Desprendimientos aparentes. Especificaciones según proyecto. Al menos 10 medidas ninguna inferior limite.(Medidas habituales 10/20 mm en pilares/cerchas)
	Toma de probetas de hormigon	EHE 08	LAB		Al menos una serie externa por proyecto	1 dia hormigonado: Control 100% 1 Serie por camion(1 serie=5 probetas). 2 dias hormigonado Control 100% 1 Serie por camion (1 serie=5 probetas) Proyectos superior 3 dias hormigonado e inferior a 1000 m2 minimo 3 lotes(1 lote =3 series) Proyectossup 1000 m2 minimo 3 lot

Fig. 23 - ITP of Concrete Activity for Modules

This plan will be supplemented, when necessary, with a “**Detail of ITP**” (SF-05 GP-2.03), where the best way to conduct inspections is clarified more accurately.

As per GP-2.03, the materials are also under control, including testing.

The type of control they should undergo includes:

- **Reception**: a **"Material Reception Program"** (SF-08) is prepared for each type of material. It shows the conditions required from the materials and the way to stockpile them, as well as the frequency of inspection and work environment conditions.
- **Specifications (tests and certifications)**: for every material subjected to tests and/or certifications it is necessary to draft a form **“Specifications of Material”** (SF-10), where the different tests, standards and specifications of that material are shown, including the specific work environment conditions necessary for the right implementation of each test.
- **Traceability**: this type of control is applied to those materials whose identification and Traceability are requirements included in the Project Quality Plan, required by the Client or where it has been considered appropriate.
- **Stockpiling method**: except in special cases, handling and storage of materials require no treatment other than to invoke the standards of good practice.

DRAGADOS	LISTADO DE MATERIALES					PLAN	297/100
						HOJA	1
						VERSIÓN	3
						FECHA	marzo-14
OBRA:	FACTORÍA DE LAS CABEZAS DE SAN JUAN					CÓDIGO:	297/100
Nº	**MATERIAL**	**RECEPCIÓN**	**ESPECIFICACIÓN**	**TRAZABILIDAD**	**PROC.**	**ACOPIO**	**FECHA LIMITE PREPAR.**
1	CEMENTO	X	X		P	S	16/04/2014
2	ARENA	X	X		P	I	16/04/2014
3	FIBRA DE VIDRIO	X	X		P	C	16/04/2014
4	ADITIVO SUPERPLASTIFICANTE	X	X		P	C	16/04/2014
5	CARRILES DE ANCLAJE	X	X		P	C	28/04/2014
6	BASTIDORES	X	X		P	C	28/04/2014
7	PIGMENTO	X	X		P	C	28/04/2014
8	POLIESTIRENO EXPANDIDO	X	X		P	C	16/04/2014

ACOPIOS:

I = Intemperie
C = A cubierto
E = Especial
S = Ensilado
NA = No aplica

PROCEDENCIA

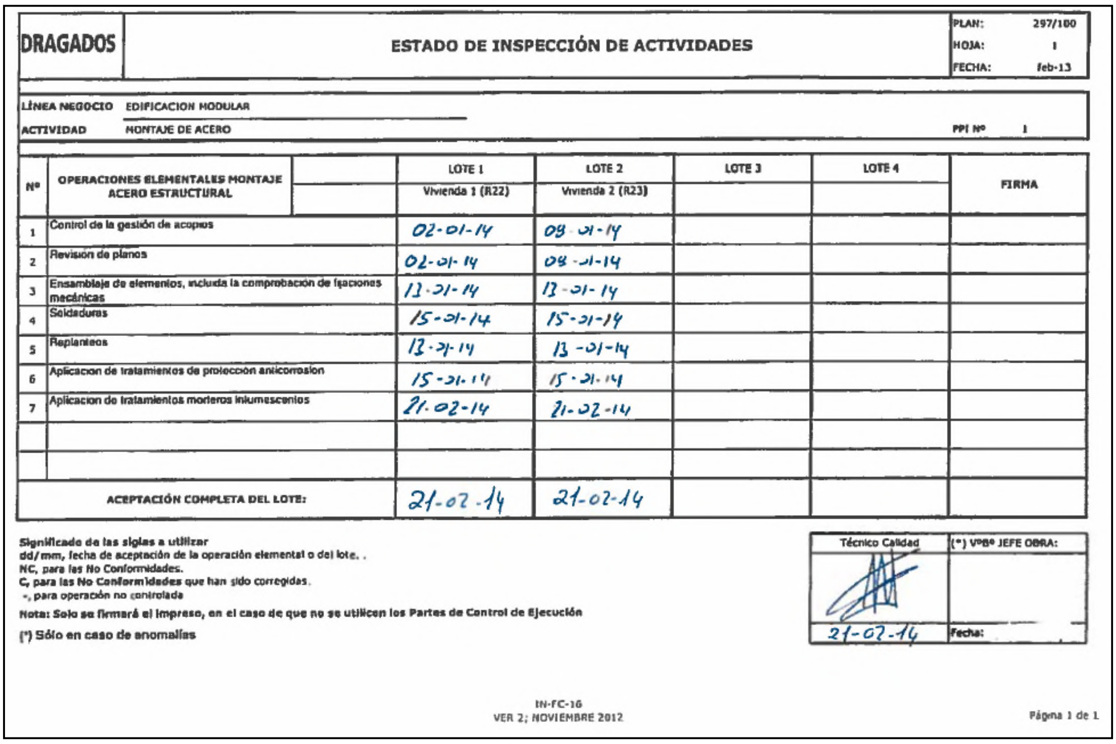
P = Propio
S = Subcontratista

Fig. 24 - Material List of GRC

DRAGADOS	PROGRAMA DE RECEPCIÓN DE MATERIALES			PLAN	297/100
				HOJA	1
				VERSIÓN	3
				FECHA	mar-14
OBRA:	FACTORIA DE LAS CABEZAS DE SAN JUAN -SEVILLA-			CÓDIGO:	297/100

Nº	MATERIAL	FRECUENCIA DE INSPECCIÓN	CONDICIONES DE ACOPIO	ESPECIFICACIONES
0	Todos los materiales	Todos los suministros, 10% del material	Salvo especificación en contrario, en almacén, en su embalaje original.	**Inspección básica**, aplicacable a todos los materiales especialmente a los incluidos en el "Listado de materiales" Comprobar que las cantidades y el material suministrado coinciden con el albarán Comprobar el peso de al menos 2 unidades en materiales ensacados; tolerancia: 2,5% Embalaje en perfecto estado, materiales con ausencia de daños aparentes, en buen estado, sin roturas ni desperfectos **Conformidad y aceptación del material,** En caso de que el material sea conforme se procederá a la firma del albarán. En caso de rechazo del material no se firmará el albarán y se levantará la correspondiente NC. En caso de aceptarse el material aún presentado algún tipo no conformidad, de se realizará la correspondiente anotación en el albarán, se dará de alta la NC y se etiquetará el material convenientemente para evitar su uso indebido.
1	HORMIGON PREPARADO	Todos los camiones	NO PROCEDE	**Procedencia** (planta y nombre del fabricante): HORMIGONES ARLOW, S.L. **Denominación del producto:** habitualmente HA-25/B/20/IIa **Inspección:** * Se comprobarán las características del hormigón: - Tipo de hormigón suministrado - Tipo y cantidad máxima de cemento - Relación a/c * Hora de salida de la planta/hora de vertido inferior a 90minutos * Aspecto externo y tolerancias: Cono: Seco: 0-2. Plastico (P): 3-5. Blando(B): 6-9. Fluido(F): 10-15. Líquido(L): 15-20. Tolerancia de cono: ± 1 cm para S, P y B, y ± 2 cm para B. * Comprobación dimensional, máxima desviación admisible por unidad de suelo 5mm ¿largo y ancho?

Fig. 25 - Material Reception Program of Modules



DRAGADOS	ESTADO DE INSPECCIÓN DE ACTIVIDADES	PLAN: 297/100 HOJA: 1 FECHA: feb-13

LÍNEA NEGOCIO EDIFICACION MODULAR
ACTIVIDAD MONTAJE DE ACERO PPI Nº 1

Nº	OPERACIONES ELEMENTALES MONTAJE ACERO ESTRUCTURAL	LOTE 1 Vivienda 1 (R22)	LOTE 2 Vivienda 2 (R23)	LOTE 3	LOTE 4	FIRMA
1	Control de la gestión de acopios	02-01-14	08-01-14			
2	Revision de planos	02-01-14	08-01-14			
3	Ensamblaje de elementos, incluida la comprobación de fijaciones mecánicas	13-01-14	13-01-14			
4	Soldaduras	15-01-14	15-01-14			
5	Replanteos	13-01-14	13-01-14			
6	Aplicacion de tratamientos de protección anticorrosion	15-01-14	15-01-14			
7	Aplicacion de tratamientos morteros intumescentes	21-02-14	21-02-14			
	ACEPTACIÓN COMPLETA DEL LOTE:	21-02-14	21-02-14			

Significado de las siglas a utilizar
dd/mm, fecha de aceptación de la operación elemental o del lote. .
NC, para las No Conformidades.
C, para las No Conformidades que han sido corregidas.
-, para operación no controlada
Nota: Solo se firmará el impreso, en el caso de que no se utilicen los Partes de Control de Ejecución
(*) Sólo en caso de anomalías

Técnico Calidad	(*) VºBº JEFE OBRA:
21-02-14	Fecha:

IN-FC-16
VER 2; NOVIEMBRE 2012

Página 1 de 1

Fig. 26 - Activity inspection Status of Steel Activity

5.2.2 Control of the received prefab elements

The examination of received prefabricated elements:

- Right element according to specifications
- In the right condition e.g.:
  - o Element has no (visual) damages
  - o Element has the right dimensions and shape (within the tolerances)
  - o Building element meets the building physical requirements
- At the right time.

Important questions are:

- Who is going to check the received elements?
- What is needed for inspection and self-instruction?
- What will be checked and how?
- What are the requirements / demanded quality/ tolerances?
- What is done with the outcome?
- What is done with the inspection data? Feedback to previous stages is very important especially in cases of deviation. Feedback without delay to prevent future errors and to take corrective actions.
- How are the measurement results integrated in the BIM model.

In case of storage of the element on-site check the right circumstances for storage.

5.2.3 Control of the construction / connection where the element has to be installed / connected to

The examinations of the construction where the prefab element has to be placed or connected:

- Control of constructional aspects;
- Right dimensions, geometry of the construction and/ or connection elements;
- Right connection material;
- Right place of construction and connection elements.

The same questions mentioned at control of received prefab elements can be asked here as well. But in this case the focus on the construction / elements or services (e.g. ducts, pipes and cables) where the prefab element has to be placed on or connected to.

5.2.4 Control of the right placement of the element

The examinations of the right placement of the element in exact the right position and / or the right connections.

See questions mentioned at "phase a".

5.2.5 Control of the connection between prefab element and construction

The examination of the connection of the prefabricated element to the construction and other connection elements

- Control of constructional aspects;
- Control of the tightness of the joints of building elements (airtightness, water tightness, damp diffusion, airborn sound insulation);
- Control of gaps around services (airtightness, water tightness, damp diffusion, airborn sound insulation);
- Control of the thermal insulation;
- Control of the tightness of the installation connections to ducts, pipes;
- Control of unwanted connections between elements to prevent impact sound insulation problems.

In the case of errors, it is important to give feedback to the previous stage and/or to the quality assessment protocol to prevent errors in the future. Therefore, feedback without delay to prevent future errors and to take corrective actions is needed.

5.3 Use-case approach

The preview validation and testing of the "INSITER methodology" (to clarify and to agree the system requirements) is based on Use-cases.

A Use-Case is a Demonstration-Case that is brought into context (story). It also defines a system, which has to be used.

Example: New panels are installed ➔ Inspection worker uses Soundbrush to verify the installation ➔ Results will be noted via a mobile form and automatically forwarded to an Information System ➔ Project Manager acknowledges the confirmation and initiates follow-up tasks.

INSITER adopts two different types of use cases:

1. **Experiments Use Cases** (Test case);
2. **Implementation Use Cases** (Demonstration case).

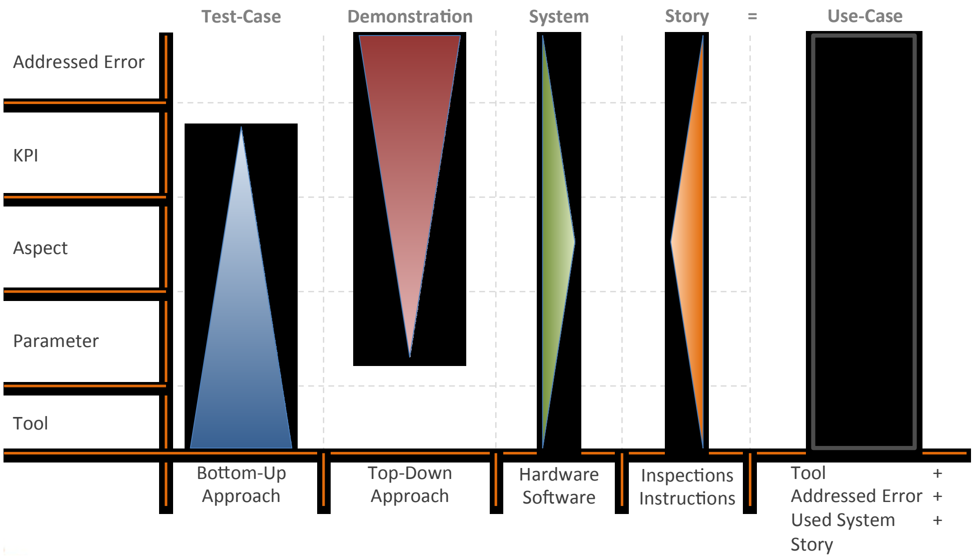


Fig. 27 – Relevant parts of a use-case

Experiments Use Cases (Test case)

It develops to support R&D and testing during INSITER project. The approach proposed is "Bottom-up" because is the "technology" that defines the Use Cases.

A Test-Case refers to a tool or a technology which should be investigated in order to get measurements (parameters) which are addressing a specific KPI.

The Test Cases will be possible available 1) in Lab; 2) in Factory and 3) on Virtual set. In detail the step as follows: 1) the Test-Case will be set up in an optimized testing environment (Lab-Test) first and if the test is successful, 2) it will be transferred to a larger test-environment (Factory). Example: Usage of Soundbrush will be tested in Lab-Test. If successful: transfer test to Factory and repeat.

The definition of Experiments Use Cases follows the steps presented:

I. Formulate an R&D question *(e.g. How to apply Augmented Reality (AR) to visualize thermal and acoustic sensor data?);*
II. Determine the testing environment to investigate this formulated R&D question *(e.g. Lab installations at UNIVPM, the so-called "refrigerator");*
III. Select a focus area within the testing environment *(e.g Joints between the prefab wall elements of the "refrigerator");*

IV. Determine which EeB KPIs apply on the selected focus area *(e.g Thermal and acoustic leakages);*

V. Limit the scope of inspection by referring to the “most frequent errors” related to the relevant EeB KPI and selected focus area *(for instance: Alignment of insulation layer at joints between prefab panels);*

VI. Define the testing instruments and data to deal with the R&D question *(e.g Thermal sensors placed at XXX positions to supply YYY data in ZZZ format; acoustic data derived from Soundbrush applied in VVV way to supply CCC data in DDD format);*

VII. Prescribe which testing protocol(s) and analysis method(s) should be employed *(e.g Integration of 3D data with acoustic/thermal imaging to be visualized next to the real-time image on XXX tablet running on ZZZ software platform);*

Following the KPIs and construction errors presented in D1.1, seven “Test case” has been defined:

1. Thermal;
2. Acoustic;
3. Air tighteness;
4. Humidity;
5. Geometry;
6. Integration of measurement result into BIM (including Model Checking);
7. Augemented Reality.

As mentioned above, all seven test cases defined will follow the following 3 stages:

- Should be setup in the Lab Test environment first;
- If the tests have proven to be successful, the next stage continues to a larger test environment. Further test cases will be set up at factory level and finally;
- All tested devices and technology will be further used for the demonstration of the implementation use cases (real life demonstrators) at the identified implementation and demonstration sites.

Implementation Use Cases (Demonstration case)

A ***Use case*** is developed to demonstrate INSITER results to (external) stakeholders for implementation / exploitation in real practice during and after INSITER project. This Use Cases will be dedicated to: 1) New construction; 2) Renovation and 3) Maintenance projects. The approach proposed is “Top-down” because is the “practice” that defines the Use Cases.

A Demonstration-Case defines a specific issue (aspect) on site, which should be investigated regarding a specific KPI. For performing a Demonstration-Case the promising tools and technologies from the Test-Cases will be used.

Example: Noise reduction of new panels should be tracked with Soundbrush which achieved good results.

The definition of Implementation Use Cases has followed the steps presented:

I. Choose a project setting *(e.g.* Building renovation);

II. Select a focus area for the chosen project setting *(e.g.* Building envelopes);

III. Determine which EeB KPIs apply on the selected focus area *(e.g.* Temperature difference);

IV. Limit the scope of inspection by referring to the 'most frequent errors' related to the relevant EeB KPI and selected focus area (for instance: Alignment of insulation layer at building façade);

V. Assign the actor to perform the inspection *(e.g.* Inspection on insulation layer should be done by worker of Façade Subcontractor);

VI. Prescribe which inspection instrument and protocols should be used by this actor *(e.g.* Inspection of the façade insulation / possible thermal bridge using XXX thermal camera according to YYY protocol (e.g. Plan-Do-Check-Act);

VII. Find a real project where this Implementation Use Case can be demonstrated *(e.g.* Renovation of the school building in Pisa, IT).

Three "Demonstration case" has been defined (WP5 input):

1. **Roof top extension Healthcare Centre**
    - Project setting: Cologne, Germany;
    - Type of project: new construction;
    - Scope and main area of inspection: Building envelope density, mounting process of pre-fab elements and application of self-instruction tool, in a new construction building;
    - Involved actors: workers;
    - Project phase: on-site assembly phase and first use (commissioning);
    - Type of procedures: self-instruction.

2. **Cartif building**
    - Project setting: Valladolid, Spain;
    - Type of project: maintenance;
    - Scope and main area of inspection: Building envelope, building physics,heat pumps, HVAC systems; inspections in an existing building and general maintenance issues;
    - Involved actors: workers, maintainers;
    - Project phase: in-use phase;
    - Type of procedures: self-inspection.

3. **School complex**
    - Project setting: Pisa, Italy;
    - Type of project: Building analysis and (possible) renovation/retrofitting;
    - Scope and main area of inspection: building envelope, existing opaque and glass prefab panels;
    - Involved actors: Specialists / technical advisors;
    - Project phase: Building envelope renovation (possible);
    - Type of procedures: self-inspection.

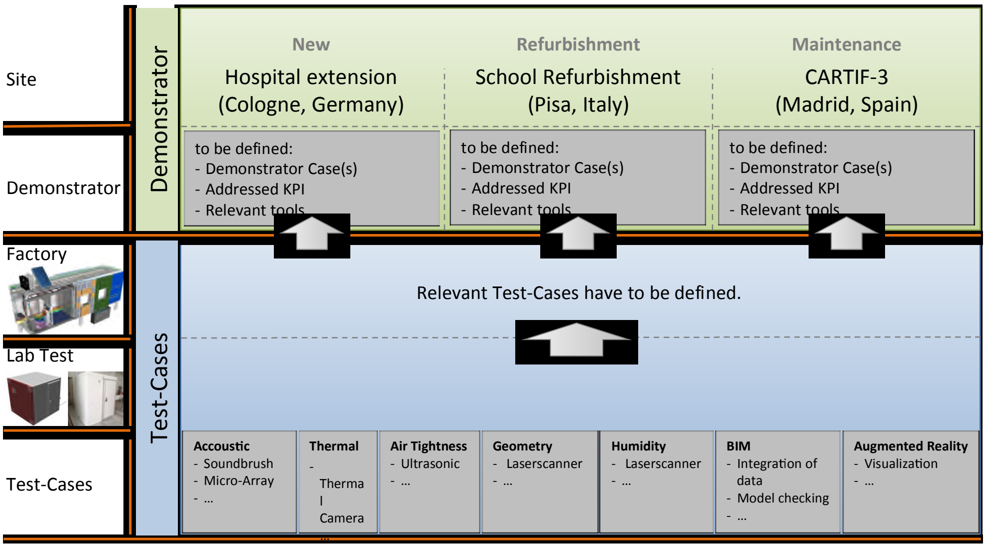


Fig. 28 – Test and Demonstrator Cases defined

Initiated to the WP3 the next action on Test-Cases regards the specifications of requirements from the use cases towards the software which has to be developed.

The Demonstration-cases will be worked out in WP5. Each Demonstration-cases project should consists of: use case expectation (objectives), instruments/simulation tools, BIM (if applicable), parameters and KPIs.

6. FOLLOW-UP RESEARCH AND DEVELOPMENT

6.1 Recommendations for quantitative methods and practical guidelines

The D1.1 has introduced (chapter 5) the innovative INSITER protocol to improve the self-inspection and self-instruction of prefab buildings. This protocol will be implemented and improved during the research project to define the self-inspection guidelines for new and existing buildings.

The main goal of the protocol proposed, organized in 8 main steps, is to improve the building quality and energy performance of prefab buildings. Other complementary goals are the reduction of construction time and costs.

It is still important to consider that INSITER aims to reduce the existing gap between the design requirements in comparison to the real construction proposing innovative methods for self-inspection (to detect errors) and self-instruction (to reduce and prevent errors).

The conceptual framework, concerning the self-inspection methodology, presents four main topic steps of the building inspection:

- Step 2: inspection at procurement, production and delivery stage of prefab components (building and MEP-HVAC);
- Step 5: inspection on virtual model where we can identify preliminary performance and detect potential clashes;
- Step 7: inspection on-site during the building construction;
- Step 8: inspection during pre-commissioning, commissioning and project delivery.

It is clear that the identification of construction defects (errors) and subsequent validation of the protocol will be supported by "quantitative methods" that propose progressive tasks to detect existing faults or construction defects on-site. The analytical methods will be developed in detail in the next D1.4 (M24) and D1.6 (M24). The "Test Cases" approach (see chapter 5) could define better the methods (and protocol) proposed that could be then validates in the "Demonstration Cases".

Despite this, it is expected that the quantitative methods, used for measuring the defects impact, will follow these main steps:

a) Identification of defect typology in relation to the related requirements, norms and standards;
b) Defect assessment using tools, instruments and software (INSITER assessment tools);
c) Defect evaluation based on the KPIs, measurements aspects and parameters, norms, standards or design technical specification.

The INSITER protocol proposes an innovative method that necessarily will be supported by practical guidelines for the real implementation of new buildings, retrofitting and/or maintenance works. This action is necessary since INSITER proposes the application, inside the process, of new technologies, like BIM and AR, as well as the integration of innovative inspection tools available on the market.

The guidelines (self-inspection and self-instruction) that will be developed in the next tasks, as well as the INSITER protocol improvement, will be very useful for all the actors involved in the process (see chapter 2.2) and particularly for the building workers. In fact the building workers will be facilitate in order to check their own work process results (self-inspection) and at the same time they will have an interactive guidance during their working process (self-instruction).

In detail, the guideline could answer to the following practical questions:

- What are the main building components and key data to be assessed to evaluate the building quality and energy performance?
- How can we apply the self-inspection and self-instruction inside all task of the building process of prefab buildings?
- How can we integrate Augmented Reality technologies in the inspection process and during the assembling of prefab components?
- How can we prevent construction errors simulating (off-site) the construction process and proposing the “preliminary inspection plan”?
- Which are the best tools to be used in specific situations (or process tasks) to detect and measure defects?
- How can we use on-site the tools proposed (practical information on installation, measurement points, data collection, etc.)?

Other crucial questions will emerge in the next months. The aim is to give the right answers in the D1.2 (M36) and D1.3 (M36).

6.2 Recommendations for tool enhancements to support INSITER protocols

INSITER will not develop new diagnostic instruments or tools but will analyse the market in order to select the best solutions to detect, measure and evaluate the construction errors (self-inspection) inside the process as well as to use innovative technologies (BIM and AR) to support the building construction (self-instruction).

The measurement and diagnostic devices will be defined according to the KPIs family and relative measurements-parameters aspects introduced in this Deliverables (chapter 4). A first selection of portable instruments to support the inspection in the construction process is already defined (e.g. thermal and infrared multispectral camera; acoustic imaging systems; 3D laser scanner; blower door test; thermal sensor and humidity sensor). At the same time it has been introduced the potential application inside the process of new technologies as BIM and AR.

Based on the identified shortcomings it is possible to remark several actions in this field to support the INSITER protocol and the future validation of the guidelines.

In WP2 (Portable and robust systems and equipment for self-inspection) it is necessary to propose a detailed analysis of the inspection tools and technologies selected, introducing their potential use for optimizing the process (how, when, where) and suggesting the correct integration of the tools and the data capturing systems.

In WP3 (User-friendly software applications for self-inspection) it is necessary to define the potential application, inside the building process and INSITER protocol, of softwares for cost monitoring, quality and energy assessments (related to the KPIs selected and the building requirements). The software selected will be useful for INSITER if correctly integrated with the BIM. For this reason, an important action to be done concerns the development of a specific interface between the software selected and the BIM.

The BIM is a crucial issue for the INSITER protocol (see step 2). Considering the preliminary introduction of the building technological system (building and MEP-HVAC components) proposed in the D1.1, it is necessary that WP4 defines the correct guideline to work out the building model (detail level and documentations) considering the building and MEP-

HVAC components that are "crucial" (see construction errors) for building quality and energy performance.

Moreover, working on existing buildings it is important to optimize the transfer of the building data captured with 3D laser scanner to the BIM. Last but not least, the potential exploitation of INSITER on the market deal with the application of AR for preventing errors. For this reason, it is very important to develop new self-instruction models based on the integration of BIM and AR.

APPENDIX 1 - Building components standards

This annex lists propose a selection of European standards regarding the condition of building components. They are grouped into several groups:

- Building condition, taking into account assessments of the building condition and quantities and guidelines to use this information for asset management
- Building components, focusing on the quality assessment of specific building components;
- Building performance, focusing on the performance of the building from a building physics point of view;
- Building materials; standards for the quality assessment of typical building materials;
- Test methods; standards describing specific test methods;
- Tools; standards describing the operation of tools.

STANDARD CODE	STANDARD TITLE
(A) BUILDING CONDITIONS	
(A.1) Building material quality	
NEN 2767-1:2011/C1:2013 nl	Condition assessment - Part 1: Methodology
NEN 2767-2:2008 nl	Condition assessment of building and installation components - Part 2: Lists of faults
NEN 3682:1990 nl	Dimensional control in the building field - General rules and guidance
UNE 41805-1-09	Building diagnosis. Part 1: General.
UNE 41805-2-09	Building diagnosis. Part 2: Historical studies.
UNE 41805-3-09	Building diagnosis. Part 3. Constructive and pathological studies
UNE 41805-4-09	Building diagnosis. Part 4 - Pathological study of the structure of the building. Land and laying of foundations
EN 15221-3:2011 en	Facility Management - Part 3: Guidance on quality in Facility Management
EN 15221-1:2006 en	Facility Management - Part 1: Terms and definitions
(A.2) Building material quantity	
NEN 3699:1993 nl	Method for measurement of net quantities of building parts, installation parts and results with specification directives
NEN 2580:2007 nl	Areas and volumes of buildings - Terms, definitions and methods of determination
DIN 277-3 2005	Areas and volumes of building - Part 3: Quantities and reference units
NEN 3682:1990 nl	Dimensional control in the building field - General rules and guidance
(B) BUILDING COMPONENTES	
(B.1) Façades	
UNE 41805-10-09	Building diagnosis - Part 10: Pathological study of the building - Nonstructural facades
(B.2) Floors	
DIN 18560-1 2009	Floor screeds in building construction - Part 1: General requirements, testing and construction
(B.3) Roofs	
UNE 136020-04	Clay roofing tiles. Code of practice for the design and fixing of roofs with clay roofing tiles
UNE 41805-9-09	Building diagnosis - Part 9 - Pathological study of the building - Roofings
DIN 18531-3 2010	Waterproofing of roofs - Sealings for non-utilized roofs - Part 3: Design, handling of materials, execution of sealings
(B.4) Windows	
UNE 85219-86 Instruction	Windows. Setting in the building
UNE 85222-85	Windows. Glazing. Assembling method
UNE 85226-87	Windows. Shutters: testing methods. Mechanical tests
UNE 85227-87	Windows. Shutters: classification according to the mechanical resistance
UNE 85229-85	Methods of testing windows. Water tightness test under static pressure repiting charge
UNE 85230-87	Windows. Sealed: terminology and definitions
UNE 85232-96	Windows. Sealing. Classification, designation and test methods of sealings.
UNE 85233-86 Instruction	Windows. Aptitude for performance and technical specifications

UNE 85234-87 Instruction	Windows, shutters and accesories. Technical documents for external carpentry of buildings
UNE 85235-87	Windows-sealing. Glazing systems classification and designation
UNE 85241-90	Windows. Preframes.
UNE 85246-1-09	Case for blinds. Part 1:Monoblock of unplasticized polyvinylchloride profiles (PVC-U) and fittings. Requirements, performance, test methods and classification.
NEN 3660:1988 nl	Window frames - Air permeability, rigidity and strength - Methods of test
NEN 3661:1988 nl	Window frames - Air permeability, water tightness, rigidity and strength - Requirements
NEN-EN 1026:2000 en	Windows and doors - Air permeability - Test method
UNE 85203-82	Methods of testing windows. Mechanical tests
UNE 85247-11	Windows and doors. Watertightness. Site test
UNE 41805-11-09	Building diagnosis - Part 11: Pathological study of the building - Carpentry of windows and locks
(B.5) Partition walls	
UNE 102043-13	Installation of construction systems with gypsum plasterboards. Partitions, wall linings and ceilings. Definitions, applications and recommendations
UNE 41805-12-09	Building diagnosis - Part 12 - Pathological study of the building. Internal partitions and finishings
DIN 4103-2 2010	Internal non-loadbearing partitions - Part 2: Partitions made of gypsum blocks
UNE 136002-95 EX	PREFABRICATED CLAY AND GYPSUM PANELS. METHODS OF TESTS.
(C) BULDING PERFORMANCE	
(C.1) General	
EN 1330-1:2014	Non destructive testing - Terminology - Part 1: List of general terms
EN 1330-2:1998	Non destructive testing - Terminology - Part 2: Terms common to the non-destructive testing methods
EN 1330-4:2010	Non-destructive testing - Terminology - Part 4: Terms used in ultrasonic testing
CEN ISO/TR 25107:2006	Non-destructive testing - Guidelines for NDT training syllabuses (ISO/TR 25107:2006)
(C.2) Energy performance and insulation	
NEN 7120+C2:2012 nl	Energy performance of buildings - Determination method
NVN 7125:2011 nl	Energy performance standard for provisions at district level - Determination method
DIN 4108-4 2013	Thermal insulation and energy economy in buildings - Part 4: Hygrothermal design values
EN-ISO 14683:2007 en	Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values
DIN 55699 2005	Application of thermal insulation composite systems
(C.3) Air tightness	
NEN 2686:1988 nl	Air leakage of buildings - Method of measurement
NEN 2690:1991 nl	Air leakage of buildings - Method of measurement of the specific air flow rate between crawl space and dwelling
EN 12114:2000 en	Thermal performance of buildings - Air permeability of building components and building elements - Laboratory test method
EN 14509:2013 en	Self-supporting double skin metal faced insulating panels - Factory made products - Specifications
SKH-BGS 1301	Assessment methods for determining airtightness 2015
(C.4) Ventilation	
NEN 8087:2001 nl	Ventilation in buildings - Determination methods for existing buildings
NEN 1087:2001 nl	Ventilation in buildings - Determination methods for new estate
NPR 1088:1999 nl	Ventilation in dwellings and residential buildings - Indications for and examples of the construction of ventilation systems
(C.5) Humidity/Moisture	
NEN 2778:2015 nl	Resistance to moisture in buildings - Determination methods
DIN 4095 1990	Planning, design and installation of drainage systems protecting structures against water in the ground
DIN 18195-1 2011	Waterproofing of buildings - Part 1: Principles, definitions, attribution of waterproofing type

DIN 18195-3 2011	Water-proofing of buildings - Part 3: Requirements of the ground and working properties of materials
DIN 18195-5 2011	Water-proofing of buildings - Part 5: Water-proofing against non-pressing water on floors and in wet areas, design and execution
DIN 18195-6 2011	Water-proofing of buildings - Part 6: Water-proofing against outside pressing water and accumulating seepage water, design and execution
DIN 18195-7 2009	Water-proofing of buildings - Part 7: Water-proofing against pressing water from the inside, dimensioning and execution
DIN 18195-8 2011	Water-proofing of buildings - Part 8: Water-proofing over joints for movements
DIN 18195-9 2010	Water-proofing of buildings - Part 9: Penetrations, transitions, connections and endings
DIN 18195-10 2011	Water-proofing of buildings - Part 10: Protective layers and protective measures
DIN 18197 2011	Sealing of joints in concrete with waterstops
(C.6) Sound insulation	
EN-ISO 16283-1:2014 en	Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation
EN-ISO 3382-2:2008 en	Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinairy rooms
EN-ISO 3382-3	Acoustics - Measurement of room acoustic parameters - Part 3: Open plan offices
EN-ISO 18233:2006 en	Acoustics - Application of new measurement methods in building and room acoustics
EN ISO 15186-2:2010	Acoustics - Measurement of sound insulation in buildings and of building elements using sound intensity - Part 2: Field measurements (ISO 15186-2:2003)
DIN 4109 1989	Sound insulation in buildings; requirements and testing
DIN 4109 Beiblatt 2:1989-11	Sound insulation in buildings; guidelines for planning and execution; proposals for increased sound insulation; recommendations for sound insulation in personal living and working areas
(C.7) Fire safety	
NEN 6059-1:2015 nl	Assessment of fire safety of buildings - Part 1: Initial assessment of fire safety of buildings
NEN 6059-2:2015 nl	Assessment of fire safety of buildings - Part 2: Condition assessment of fire safety of buildings
DIN 4102-6 1977	Fire Behaviour of Building Materials and Building Components; Ventilation Ducts; Definitions, Requirements and Tests
DIN 18095-1 1988	Smoke control doors; concepts and requirements
(C.8) Vibrations	
ISO 4866:2010	Mechanical vibration and shock -- Vibration of fixed structures -- Guidelines for the measurement of vibrations and evaluation of their effects on structures
UNI 9916:2014	Criteria of measurement and evaluation of effects of vibrations on buildings
DIN 4150-3:1999-02	Vibration in buildings - Part 3: Effects on structures
SN 640 312 a : 1992	Vibration Effects on buildings - (Erschütterungseinwirkungen auf Bauwerke)
BS 7385-2:1993	Title: Evaluation and measurement for vibration in buildings. Guide to damage levels from ground borne vibration
(D) BULDING MATERIALS	
(D.1) Concrete	
EN 12504-1:2009	Testing concrete in structures - Part 1: Cored specimens - Taking, examining and testing in compression
EN 12504-2:2012	Testing concrete in structures - Part 2: Non-destructive testing - Determination of rebound number
EN 12504-3:2005	Testing concrete in structures - Part 3: Determination of pull-out force
EN 12504-4:2004	Testing concrete - Part 4: Determination of ultrasonic pulse velocity
EN 12390-1:2012	Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds
EN 12390-2:2009	Testing hardened concrete - Part 2: Making and curing specimens for strength tests
EN 12390-3:2009	Testing hardened concrete - Part 3: Compressive strength of test specimens
EN 12390-4:2000	Testing hardened concrete - Part 4: Compressive strength - Specification for testing machines
EN 12390-5:2009	Testing hardened concrete - Part 5: Flexural strength of test specimens
EN 12390-6:2009	Testing hardened concrete - Part 6: Tensile splitting strength of test specimens

EN 12390-7:2009	Testing hardened concrete - Part 7: Density of hardened concrete
EN 12390-8:2009	Testing hardened concrete - Part 8: Depth of penetration of water under pressure
CEN/TS 12390-9:2006	Testing hardened concrete - Part 9: Freeze-thaw resistance - Scaling
CEN/TS 12390-10:2007	Testing hardened concrete - Part 10: Determination of the relative carbonation resistance of concrete
CEN/TS 12390-11:2010	Testing hardened concrete - Part 11: Determination of the chloride resistance of concrete, unidirectional diffusion
EN 12390-13:2013	Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression
UNI 9944:1992	Corrosion and protection of reinforcing steel in concrete. Determination of the carbonation depth and of the chlorides penetration profile in concrete.
ASTM C876 - 09	Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete
UNE 41805-6-09	Building diagnosis - Part 6 - Pathological study of the structure of the building - Concrete structures
DIN 1045-3 2012	Concrete, reinforced and prestressed concrete structures - Part 3: Execution of structures - Application rules for DIN EN 13670
(D.2) Stone	
UNI 11121:2004	Cultural heritage - natural and artificial stone materials - Site determination of water content with the calcium carbide method
UNE 22203-11	Natural stone products. Construction of slabs for facade with natural stone
(D.3) Gypsum	
UNE 102037-85	Building plaster and building molains plaster. Phase analysis methods
(D.4) Wood	
UNE 41805-8-09	Building diagnosis - Part 8 - Pathological study of the structure of the building - Wood structures
DIN 1052-10 2012	Design of timber structures - Part 10: Additional provisions
(D.5) Wood	
UNE 41805-8-09	Building diagnosis - Part 8 - Pathological study of the structure of the building - Wood structures
DIN 1052-10 2012	Design of timber structures - Part 10: Additional provisions
(D.5) Metallic structures	
UNE 41805-7-09	Building diagnosis - Part 7 - Pathological study of the structure of the building - Metallic structures
EN ISO 6892-1:2009	Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1:2009)
EN ISO 6892-2:2011	Metallic materials - Tensile testing - Part 2: Method of test at elevated temperature (ISO 6892-2:2011)
EC 1-2015 UNI EN ISO 9513:2013	Metallic materials - Calibration of strain gauges used in uniaxial testing
(D.6) Masonry	
UNE 41805-5-09	Building diagnosis - Part 5 - Pathological study of the structure of the building - Masonry units.
DIN 1053-4 2013	Masonry - Part 4: Prefabricated masonry compound units
(E) TOOLS	
ASTM E741-11	Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution
EN 13187:1998 en	Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method
ASTM C1153-10	ASTM Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging
EN-ISO 9972:2015 en (was NEN-EN 13829:2000 en)	Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method
ASTM E1827-11	Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door
ISO 5348:1998	Mechanical vibration and shock -- Mechanical mounting of accelerometers
UNI 11568:2015	Vibrations - Instrumentation and analysis for the measurement of vibration - Measure instruments
EN 1330-4:2010	Non-destructive testing - Terminology - Part 4: Terms used in ultrasonic testing
EN ISO 3452-4:1998	Non-destructive testing - Penetrant testing - Part 4: Equipment (ISO 3452-4:1998)

EN ISO 9934-3:2002	Non-destructive testing - Magnetic particle testing - Part 3: Equipment (ISO 9934-3:2002
EN 1087-1:1995 en	Particleboards - Determination of moisture resistance - Part 1: Boil test
EN ISO 3059:2012	Non-destructive testing - Penetrant testing and magnetic particle testing - Viewing conditions (ISO 3059:2012)
EN ISO 3452-1:2013	Non-destructive testing - Penetrant testing - Part 1: General principles (ISO 3452-1:2013)
EN ISO 3452-2:2013	Non-destructive testing - Penetrant testing - Part 2: Testing of penetrant materials (ISO 3452-2:2013)
EN ISO 3452-3:2013	Non-destructive testing - Penetrant testing - Part 3: Reference test blocks (ISO 3452-3:2013)
EN ISO 3452-4:1998	Non-destructive testing - Penetrant testing - Part 4: Equipment (ISO 3452-4:1998)
EN ISO 3452-5:2008	Non-destructive testing - Penetrant testing - Part 5: Penetrant testing at temperatures higher than 50 degrees C (ISO 3452-5:2008)
EN ISO 3452-6:2008	Non-destructive testing - Penetrant testing - Part 6: Penetrant testing at temperatures lower than 10 degrees C (ISO 3452-6:2008)
EN ISO 12706:2009	Non-destructive testing - Penetrant testing - Vocabulary (ISO 12706:2009)
EN 1330-7:2005	Non-destructive testing - Terminology - Part 7: Terms used in magnetic particle testing
EN ISO 9934-1:2001/A1:2003	Non-destructive testing - Magnetic particles testing - Part 1: General principles (ISO 9934-1:2003)
EN ISO 9934-2:2002	Non-destructive testing - Magnetic particle testing - Part 2: Detection media (ISO 9934-2:2002)
EN ISO 9934-3:2002	Non-destructive testing - Magnetic particle testing - Part 3: Equipment (ISO 9934-3:2002
ISO 10878:2013	Non-destructive testing -- Infrared thermography -- Vocabulary
EN 13187:1998	Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method (ISO 6781:1983 modified)
ISO 10878:2013	Non-destructive testing -- Infrared thermography -- Vocabulary
EN 13187:1998	Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method (ISO 6781:1983 modified)
ISO 10878:2013	Non-destructive testing -- Infrared thermography -- Vocabulary
EN 13187:1998	Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method (ISO 6781:1983 modified)
DIN 4150-3:1999-02	Vibration in buildings - Part 3: Effects on structures
SN 640 312 a : 1992	Vibration Effects on buildings - (Erschütterungseinwirkungen auf Bauwerke)
BS 7385-2:1993	Title : Evaluation and measurement for vibration in buildings. Guide to damage levels from groundborne vibration
EN ISO 15186-2:2010	Acoustics - Measurement of sound insulation in buildings and of building elements using sound intensity - Part 2: Field measurements (ISO 15186-2:2003)
ASHRAE 202	Commissioning Process for Buildings and Systems, 22 Jun 2013
UFC 1-200-02	High Performance and Sustainable Building Requirements

APPENDIX 2 - MEP-HVAC standards

This annex lists propose a selection of European standards regarding the condition of MEP-HVAC compontens. They are divided in:

- Dutch standards;
- Spanish standards;
- German standards;
- Italian standards.

DUTCH STANDARDS
Code: NEN 2767-1:2011/C1:2013 nl - Condition assessment - Part 1: Methodology and Part 2: Lists of faults **Area:** MEP/HVAC Norms **Title:English:**
Code: NEN 3682:1990 nl - Dimensional control in the building field - General rules and guidance **Area:** MEP/HVAC Norms
Code: NEN 6059-1:2015 nl - Assessment of fire safety of buildings - Part 1: Initial assessment of fire safety of buildings; Part 2: Condition assessment of fire safety of buildings **Area:** MEP/HVAC Norms
Code: NEN 6059 is a tool in order to inspect existing building uniformly. Benchmarking of buildings on the aspect of fire safety is possible. All fixed fire safety measures (e.g. fire compartment, sprinkler systems etc.) in a building are included in the fire safety scan. The fire safety scan is done in one day. The fire safety scan is limited to a visual check of the building and a check of all documents which prove the fire safety of the building. Calculations are not part of the first safety scan. **Area:** MEP/HVAC Norms
Code: NEN 3699:1993 nl - Method for measurement of net quantities of building parts, installation parts and results with specification directives **Area:** MEP/HVAC Norms
Code: NEN 7120+C2:2012 nl - Energy performance of buildings - Determination method **Area:** MEP/HVAC Norms
Code: NEN 2686:1988 nl - Air leakage of buildings - Method of measurement **Area:** MEP/HVAC Norms
Code: NEN 3660:1988 nl - Window frames - Air permeability, rigidity and strength - Methods of testIn this standard methods are described to assess façade infills, such as windows and doors, to be installed in the façades. The standard consists of methods to test: a. air permeability; b. stiffness; c. strength. The standard is applicable to vertically positioned façade infills materialised as such as they will be applied in residential building. These façade infills usually consist of a framework and infill of different materials and are intended to close a façade opening in order to from a façade. Independent from the type of material, the standard applies to moving and fixed elements in the façade. The standard does not apply to the joint between the façade infills and their surrounding construction. **Area:** MEP/HVAC Norms
Code: NEN-EN-ISO 9972:2015 en- Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method **Area:** MEP/HVAC Norms
Code: NEN-EN-ISO 9972 is intended for the measurement of the air permeability of buildings or parts of buildings in the field. It specifies the use of mechanical pressurization or depressurization of a building or part of a building. It describes the measurement of the resulting air flow rates over a range of indoor-outdoor static pressure differences. This International Standard is intended for the measurement of the air leakage of building envelopes of single-zone buildings. For the purpose of this International Standard, many multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones. International Standard does not address evaluation of air permeability of individual components. **Area:** MEP/HVAC Norms
Code: ASTM E1827-11 - Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door **Area:** MEP/HVAC Norms
Code: ASTM E741-11 - Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution **Area:** MEP/HVAC Norms
Code: NEN-EN-ISO 16283-1:2014 en - Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation **Area:** MEP/HVAC Norms
Code: NEN-EN-ISO 16283-1 specifies procedures to determine the airborne sound insulation between two rooms in a building using sound pressure measurements. It is intended for room volumes in the range from 10 to 250 m3 in the frequency range from 50 to 5 000 Hz. The test results can be used to quantify, assess and compare the airborne sound insulation in unfurnished or furnished rooms where the sound field may, or may not approximate to a diffuse field. The measured airborne sound insulation is frequency-dependent and can be converted into a single number to characterise the acoustic performance using the rating procedures in ISO 717-1 **Area:** MEP/HVAC Norms
Code: ISSO-Publicatie 31: Meetpunten en meetmethoden voor klimaatinstallaties **Area:** Heating Systems

Code: ISSO- Publicatie 68: Energetisch optimale stook- en koellijnen voor klimaatinstallaties in kantoorgebouwen **Area:** Heating Systems
Code: ISSO- Publicatie 71: Selectie van energetisch optimale warmteopwekkingsinstallaties voor kantoorgebouwen **Area:** Heating Systems
Code: ISSO- Publicatie 81: Handboek integraal ontwerpen van warmtepompinstallaties voor de utiliteitsbouw **Area:** Heating Systems
Code: CEN-EN 14336: 2004: Verwarmingssystemen in gebouwen - Installatie en inbedrijfstelling van watervoerende verwarmingssystemen **Area:** Heating Systems
Code: ISSO-publicatie 55.1: Praktijkhandleiding legionellapreventie in leidingwater **Area:** Heating Systems
Code: ISSO-publicatie 65: Inregelen van ontwerpvolumestromen in warmwaterverwarmingsinstallaties' **Area:** Heating Systems
Code: NEN 12464-1: Licht en verlichting - Werkplekverlichting - deel 1: werkplekken binnen **Area:** Lighting systems
Code: NEN 12464-2: Licht en verlichting - Werkplekverlichting - deel 2: werkplekken buiten **Area:** Lighting systems
Code: CEN-EN 12599: Ventilation for buildings Test procedures and measuring methods for handing over installed ventilation and air conditioning systems **Area:** Lighting systems
Code: NEN 3140: Bedrijfsvoering van elektrische installaties - Laagspanning **Area:** Electrical installations
Code: NEN 1010: Elektrische installaties voor laagspanning - Nederlandse implementatie van de HD-IEC 60364-reeks **Area:** Electrical installations
Code: NEN-EN 12175: 'Zuurkasten' **Area:**Zuurkasten
Code: NPR 4500: 'Zuurkasten - eisen, beproeving en aanbevelingen bij plaatsing, gebruik en onderhoud van zuurkasten in laboratoria - Toeliching bij NEN-EN14175 Zuurkasten'. **Area:**Zuurkasten
Code: CEN/TS 14175-5: 'Aanbevelingen voor installatie en onderhoud'. **Area:**Zuurkasten
Code: NEN EN 12469: 'Biotechnologie – Prestatie-eisen voor microbiologische veiligheidswerkkasten'. **Area:**Zuurkasten
Code: ISSO-publicatie 31: 'Meetpunten en meetmethoden voor klimaatinstallaties'. **Area:** Koelsystemen en gebouw gebonden koelruimten
Code: ISSO-publicatie 31: 'Meetpunten en meetmethoden voor klimaatinstallaties'. **Area:** Geautomatiseerde regelsystemen
Code: ISSO-publicatie 68: 'Energetisch optimale stook- en koellijnen voor klimaatinstallaties in kantoorgebouwen'. **Area:** Geautomatiseerde regelsystemen
Code: ISSO-publicatie 69: 'Model voor de beschrijving van de werking van een klimaatinstallatie'. **Area:** Geautomatiseerde regelsystemen
Code: CEN-EN 50491: 'General requirements for Home and Building **Area:** Geautomatiseerde regelsystemen
Code: NEN 1006 **Area:** Waterinstallaties
Code: NEN 2535 Brandmeldinstallatie **Area:** Brandveiligheid
Code: NEN 2575 Ontruimingsalarminstallatie **Area:** Brandveiligheid
Code: NPR 2576 Functiebehoud bij brand **Area:** Brandveiligheid
Code: NEN 1010 **Area:**Noodverlichting
Code: ISSO - instructieboek noodverlichtingsinstallatie **Area:**
Code: NEN1898 5.2 – 5.6 (rest van de norm niet!) **Area:**
SPANISH STANDARDS
Code: UNE 9310-92 **Area:** HVAC **Title:** Instalaciones transmisoras de calor mediante líquido diferente del agua. **English:** HEAT TRANSFER INSTALLATIONS WORKING WITH ORGANIC HEAT TRANSFER FLUIDS.
Code: UNE 19800-89 **Area:** HVAC **Title:** Válvulas de accionamiento manual para radiadores de instalaciones de calefacción. Características y métodos de ensayo. **English:** MANUALLY HANDLED VALVES FOR HEATING INSTALLATIONS CHARACTERISTICS AND TEST METHODS
Code: UNE 20460/4-45-90 **Area:** HVAC **Title:** Instalaciones eléctricas en edificios. Protección para garantizar la seguridad. Protección contra las bajadas de tensión. **English:** ELECTRICAL INSTALLATIONS OF BUILDINGS. PROTECTION FOR SAFETY. PROTECTION AGAINST UNDERVOLTAGE
Code: UNE 20460/4-46-02 **Area:** HVAC **Title:** Instalaciones eléctricas en edificios. Parte 4: Protección para garantizar la seguridad. Capítulo 46: Seccionamiento y mando. **English:** Electrical installations of buildings. Part 4: Protection for safety. Chapter 46: Isolation and switching.
Code: UNE 20460/4-473-90 **Area:** HVAC **Title:** Instalaciones eléctricas en edificios. Protección para garantizar la seguridad. Aplicación de las medidas de protección. Protección contra las sobreintensidades. **English:**
Code: UNE 20460/7-703-06 **Area:** HVAC **Title:** Instalaciones eléctricas en edificios. Reglas para las instalaciones y emplazamientos especiales. Locales que contienen radiadores para saunas. **English:** Electrical installations of buildings -- Part 7-703: Requirements for special installations or locations - Rooms and cabins containing sauna heaters
Code: UNE 20481-90 **Area:** HVAC **Title:** Instalaciones eléctricas en edificios. Campos de tensiones. **English:** VOLTAGE BANDS FOR ELECTRICAL INSTALLATIONS OF BUILDINGS

Code: UNE 53331-97 IN **Area:** HVAC **Title:** Plásticos. Tuberías de poli(cloruro de vinilo) (PVC) no plastificado y polietileno (PE) de alta y media densidad. Criterio para la comprobación de los tubos a utilizar en conducciones con y sin presión sometidos a cargas externas. **English:** PLASTICS. UNPLASTIZED POLY(VINYL CHLORIDE) AND HIGH AND MEDIUM DENSITY POLYETHYLENE (PE) PIPES. CRITERION FOR THE ASSESSMENT OF PIPES FOR PLASTICS PIPING SYSTEMS WITH CAR WITHOUT PRESSURE UNDER EXTERNAL LOADS.
Code: UNE 53331-02 IN Erratum **Area:** HVAC **Title:** Plásticos. Tuberías de poli(cloruro de vinilo) (PVC) no plastificado y polietileno (PE) de alta y media densidad. Criterio para la comprobación de los tubos a utilizar en conducciones con y sin presión sometidos a cargas externas. **English:** Plastics. Unplastized poly(vinyl chloride) and high and medium density polyethylene (PE) pipes. Criterion for the assessment of pipes for plastics piping systems with car without pressure under external loads.
Code: UNE HD 60364-1-09 **Area:** HVAC **Title:** Instalaciones eléctricas de baja tensión. Parte 1: Principios fundamentales, determinación de las características generales, definiciones. **English:** Low-voltage electrical installations -- Part 1: Fundamental principles, assessment of general characteristics, definitions
Code: UNE HD 60364-4-41-10 **Area:** HVAC **Title:** Instalaciones eléctricas de baja tensión. Parte 4-41: Protección para garantizar la seguridad. Protección contra los choques eléctricos. **English:** Low-voltage electrical installations -- Part 4-41: Protection for safety - Protection against electric shock
Code: UNE HD 60364-5-54-11 **Area:** HVAC **Title:** Instalaciones eléctricas de baja tensión. Parte 5-54: Selección e instalación de los equipos eléctricos. Puesta a tierra, conductores de protección y conductores de equipotencialidad. **English:** Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors
Code: UNE HD 60364-6-09 **Area:** HVAC **Title:** Instalaciones eléctricas de baja tensión. Parte 6: Verificación. **English:** Low voltage electrical installations -- Part 6: Verification
Code: UNE HD 60364-7-706-09 **Area:** HVAC **Title:** Instalaciones eléctricas de baja tensión. Parte 7-706: Requisitos para instalaciones o emplazamientos especiales. Recintos conductores de dimensiones reducidas. **English:** Low-voltage electrical installations -- Part 7-706: Requirements for special installations or locations - Conducting locations with restricted movement
Code: UNE 86602-85 **Area:** HVAC **Title:** Maquinaria frigorífica de compresión mecánica.Placas de identificación. **English:** REFRIGERATING MACHINERY OF MECHANICAL COMPRESSION. IDENTIFICATION PLATES
Code: UNE 86608-85 **Area:** HVAC **Title:** Maquinaria frigorífica de compresión mecánica.Aislamiento térmico. **English:** REFRIGERATING MACHINERY OF MECHANICAL COMPRESSION. THERMAL INSULATION
Code: UNE 86609-85 **Area:** HVAC **Title:** Maquinaria frigorífica de compresión mecánica.Fraccionamiento de potencia. **English:** REFRIGERATING MACHINERY OF MECHANICAL COMPRESSION. FRACTION POWER
Code: UNE 100001-01 **Area:** HVAC **Title:** Climatización. Condiciones climáticas para proyectos. **English:** Limit weather conditions for projects.
Code: UNE 100002-88 **Area:** HVAC **Title:** Climatización grados-día base 15º C. **English:** AIR CONDITIONING. DEGREES DAY BASED AT 15ºC
Code: UNE 100020-05 **Area:** HVAC **Title:** Climatización. Sala de máquinas. **English:** Air conditioning. Machine rooms.
Code: UNE 100100-00 **Area:** HVAC **Title:** Climatización. Código de colores. **English:** Air conditioning. Colour code.
Code: UNE 100152-04 IN **Area:** HVAC **Title:** Climatización. Soportes de tuberías. **English:** AIR CONDITIONING. PIPE SUPPORT SPACING
Code: UNE 100153-04 IN **Area:** HVAC **Title:** Climatización. Soportes vibratorios. Criterio de selección. **English:** AIR CONDITIONING. VIBRATION ISOLATORS. DESIGN CRITERIA.
Code: UNE 100155-04 **Area:** HVAC **Title:** Climatización. Diseño y cálculo de sistemas de expansión. **English:** AIR CONDITIONING. DESIGN AND CALCULATION OF EXPANSION TANKS.
Code: UNE 100156-04 IN **Area:** HVAC **Title:** Climatización. Dilatadores. Criterios de diseño. **English:** Air conditioning. Expansion joints. Design criteria.
Code: UNE 100165-04 **Area:** HVAC **Title:** Climatización. Extracción de humos y ventilación de cocinas. **English:** Air conditioning. Fume extraction and ventilation for kitchens.
Code: UNE 100166-04 **Area:** HVAC **Title:** Climatización. Ventilación de aparcamientos. **English:** AIR CONDITIONING. VENTILATION FOR PARKINGS
Code: UNE 100171-89 IN **Area:** HVAC **Title:** Climatización. Aislamiento térmico. Materiales y colocación. **English:** AIR CONDITIONING. THERMAL ISOLATION. ERECTION OF INSOLATING MATERIALS
Code: UNE 100171-92 Erratum **Area:** HVAC **Title:** Climatización. Aislamiento térmico. Materiales y colocación. **English:** AIR CONDITIONING. THERMAL ISOLATION. ERECTION INSOLATING MATERIALS
Code: UNE 100172-89 **Area:** HVAC **Title:** Climatización. Revestimiento termoacústico interior de conductos. **English:** AIR CONDITIONING. DUCT LINER THERMOACOUSTIC APPLICATION
Code: UNE 100705-91 **Area:** HVAC **Title:** Climatización. Medición del caudal de aire en rejillas o difusores. Método de compensación de la presión. **English:** AIR CONDITIONING. MEASURE OF THE VOLUME FLOW AIR IN GRILLES OR DIFFUSERS. METHOD OF THE PRESSURE COMPENSATION.

GERMAN STANDARDS

Code: DIN 15221-1 **Area:** HVAC **Title:** Facility Management - Teil 1: Begriffe; Deutsche Fassung EN 15221-1:2006 **English:** Facility Management - Part 1: Terms and definitions; German version EN 15221-1:2006

Code: DIN 15221-2 **Area:Title:** Leitfaden zur Ausarbeitung von Facility Management-Vereinbarungen; Deutsche Fassung EN 15221-2:2006 **English:** Facility Management - Part 2: Guidance on how to prepare Facility Management agreements; German version EN 15221-2:2006

Code: DIN 277-3:2005-04 **Area:Title:** Grundflächen und Rauminhalte von Bauwerken im Hochbau - Teil 3: Mengen und Bezugseinheiten **English:** Areas and volumes of building - Part 3: Quantities and reference units

Code: DIN 1045-3:2012-03 **Area:Title:** Tragwerke aus Beton, Stahlbeton und Spannbeton - Teil 3: Bauausführung - Anwendungsregeln zu DIN EN 13670 **English:** Concrete, reinforced and prestressed concrete structures - Part 3: Execution of structures - Application rules for DIN EN 13670

Code: DIN 1052-10:2012-05 **Area:Title:** Herstellung und Ausführung von Holzbauwerken - Teil 10: Ergänzende Bestimmungen **English:** Design of timber structures - Part 10: Additional provisions

Code: DIN 1053-4:2013-04 **Area:Title:** Mauerwerk - Teil 4: Fertigbauteile **English:** Masonry - Part 4: Prefabricated masonry compound units

Code: DIN 4095:1990-06 **Area:Title:** Baugrund; Dränung zum Schutz baulicher Anlagen; Planung, Bemessung und Ausführung **English:** Planning, design and installation of drainage systems protecting structures against water in the ground

Code: DIN 4102-6:1977-09 **Area:Title:** Brandverhalten von Baustoffen und Bauteilen; Lüftungsleitungen, Begriffe, Anforderungen und Prüfungen **English:** Fire Behaviour of Building Materials and Building Components; Ventilation Ducts; Definitions, Requirements and Tests

Code: DIN 4103-2:2010-11 **Area:Title:** Nichttragende innere Trennwände - Teil 2: Trennwände aus Gips-Wandbauplatten **English:** Internal non-loadbearing partitions - Part 2: Partitions made of gypsum blocks

Code: DIN 4108-4:2013-02 **Area:Title:** Wärmeschutz und Energie-Einsparung in Gebäuden - Teil 4: Wärme- und feuchteschutztechnische Bemessungswerte **English:** Thermal insulation and energy economy in buildings - Part 4: Hygrothermal design values

Code: DIN 4109:1989-11 **Area:Title:** Schallschutz im Hochbau; Anforderungen und Nachweise **English:** Sound insulation in buildings; requirements and testing

Code: DIN 4420-1:2004-03 **Area:Title:** Arbeits- und Schutzgerüste - Teil 1: Schutzgerüste - Leistungsanforderungen, Entwurf, Konstruktion und Bemessung **English:** Service and working scaffolds - Part 1: Service scaffolds - Performance requirements, general design, structural design

Code: DIN 18095-1:1988-10 **Area:Title:** Türen; Rauchschutztüren; Begriffe und Anforderungen **English:** Smoke control doors; concepts and requirements

Code: DIN 18195-1:2011-12 **Area:Title:** Bauwerksabdichtungen - Teil 1: Grundsätze, Definitionen, Zuordnung der Abdichtungsarten **English:** Waterproofing of buildings - Part 1: Principles, definitions, attribution of waterproofing types

Code: DIN 18195-2:2009-04 **Area:Title:** Bauwerksabdichtungen - Teil 2: Stoffe **English:** Water-proofing of buildings - Part 2: Materials

Code: DIN 18195-3:2011-12 **Area:Title:** Bauwerksabdichtungen - Teil 3: Anforderungen an den Untergrund und Verarbeitung der Stoffe **English:** Water-proofing of buildings - Part 3: Requirements of the ground and working properties of materials

Code: DIN 18195-5:2011-12 **Area:Title:** Bauwerksabdichtungen - Teil 5: Abdichtungen gegen nichtdrückendes Wasser auf Deckenflächen und in Nassräumen, Bemessung und Ausführung **English:** Water-proofing of buildings - Part 5: Water-proofing against non-pressing water on floors and in wet areas, design and execution

Code: DIN 18195-6:2011-12 **Area:Title:** Bauwerksabdichtungen - Teil 6: Abdichtungen gegen von außen drückendes Wasser und aufstauendes Sickerwasser, Bemessung und Ausführung **English:** Water-proofing of buildings - Part 6: Water-proofing against outside pressing water and accumulating seepage water, design and execution

Code: DIN 18195-7:2009-07 **Area:Title:** Bauwerksabdichtungen - Teil 7: Abdichtungen gegen von innen drückendes Wasser, Bemessung und Ausführung **English:** Water-proofing of buildings - Part 7: Water-proofing against pressing water from the inside, dimensioning and execution

Code: DIN 18195-8:2011-12 **Area:Title:** Bauwerksabdichtungen - Teil 8: Abdichtungen über Bewegungsfugen **English:** Water-proofing of buildings - Part 8: Water-proofing over joints for movements

Code: DIN 18195-9:2010-05 **Area:Title:** Bauwerksabdichtungen - Teil 9: Durchdringungen, Übergänge, An- und Abschlüsse **English:** Water-proofing of buildings - Part 9: Penetrations, transitions, connections and endings

Code: DIN 18197:2011-04 **Area:Title:** Abdichten von Fugen in Beton mit Fugenbändern **English:** Sealing of joints in concrete with waterstops

Code: DIN 18531-3:2010-05 **Area:Title:** Dachabdichtungen - Abdichtungen für nicht genutzte Dächer - Teil 3: Bemessung, Verarbeitung der Stoffe, Ausführung der Dachabdichtungen **English:** Waterproofing of roofs - Sealings for non-utilized roofs - Part 3: Design, handling of materials, execution of sealings

Code: DIN 18560-1:2015-11 [NEU] **Area:Title:** Estriche im Bauwesen - Teil 1: Allgemeine Anforderungen, Prüfung und Ausführung **English:** Floor screeds in building construction - Part 1: General requirements, testing and construction

Code: DIN 55699:2005-02 **Area:Title:** Verarbeitung von Wärmedämm-Verbundsystemen **English:** Application of thermal insulation composite systems

ITALIAN STANDARDS

Code: Decreto legislativo 4 luglio 2014, n°102: **Title:** Attuazione della direttiva 2012/27/CE sull'efficienza energetica che modifica le direttive 2009/125/CE e 2010/30/UE e abroga le direttive 2004/8/CE e 2006/32/CE. Il decreto stabilisce un quadro di misure per promuovere e migliorare l'efficienza energetica ai fini del conseguimento degli obbiettivi del 2020. **Area (English):** Implementation of Directive 2012/27/EC on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. The standard sets out a framework of measures to promote and improve energy efficiency in order to achieve the targets of 2020

Code: Legge 9 del 21 febbraio 2014 **Title:** conversione in legge del DL destinazione Italia (D.L. 145 del 23 dicembre 2013) **Area (English):** Conversion into law of Decree destination Italy (D. L. 145 of 23 December 2013) on urgent action to initiate the plan "Destination Italy", for the containment of electricity and gas rates, to reduce RC - car insurance premiums, for internationalization, development and digitization of businesses, as well as measures to achieve public works and EXPO 2015.

Code: Legge 90/13 **Title:** conversione, con modificazioni, del decreto legge 4 giugno 2013, n.63 **Area (English):** Conversion into law, with amendments, of Decree - Law 4 June 2013, n. 63, on urgent measures for the transposition of Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance for the definition of infringement proceedings launched by the European Commission, and other provisions social cohesion.

Code: D.P.R. 75/13 **Title:** regolamento recante disciplina dei criteri di accreditamento per assicurare la qualificazione e l'indipendenza degli esperti e degli organismi a cui affidare la certificazione energetica degli edifici, a norma dell'articolo 4, comma 1, lettera c), del D.lgs. 192/05 **Area (English):** Regulation containing rules on accreditation criteria for ensuring the qualification and independence of the experts and entities to be entrusted with the energy certification of buildings , in accordance with Article 4 , paragraph 1, letter c) of Legislative Decree no .192/05.

Code: D.P.R. 74/13 **Title:** criteri di gestione degli impianti termici **Area (English):** Manager policies of heating systems.

Code: D.L. 63/13 **Title:** disposizioni urgenti per il recepimento della Direttiva 2010/32/UE del Parlamento europeo e del Consiglio del 19 maggio 2010, sulla prestazione energetica nell'edilizia per la definizione delle procedure d'infrazione avviate dalla Commissione europea, nonché altre disposizioni in materia di coesione sociale". Nota: con il decreto viene recepita la Direttiva europea 31/2010/UE. Il documento contiene modifiche al D.Lgs. 192/05 e la proroga degli incentivi fiscali **Area (English):** Urgent measures for the transposition of Directive 2010/32/EU of the European Parliament and of the Council of 19 May 2010 on building energy performance for the definition of infringement proceedings launched by the European Commission , and other provisions on social cohesion. Note: by decree it is implemented the European Directive 31/2010 / EU . The document contains amendments to the Legislative Decree no. 192/05 and the extension of tax incentives.

Code: D.M. 22 novembre 2012 **Title:** modifiche all'allegato A del D.Lgs. 192/2005 **Area (English):** Modification of Annex A to Legislative Decree 19 August 2005, n. 192, implementing Directive 2002/91 / EC on the energy performance of buildings.

Code: D.M. 22 novembre 2012 **Title:** modifiche alle linee guida nazionali sulla certificazione **Area (English):** Modification of the Decree of 26 June 2009 on the " National Guidelines for the energy certification of buildings.

Code: D.Lgs. 104 di attuazione della direttiva 2010/30/UE **Title:** etichetta energetica **English:** Implementation of Directive 2010/30 / EU on the indication of the consumption of energy and other resources by energy-related products by labeling and standard product information relating to the products.

Code: D. Lgs. 28/2011 **Title:** Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili, recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE. Nota: il documento modifica le regola sugli obblighi previsti per la copertura energetica da fonti rinnovabili (art. 11 e all.3) e per la certificazione energetica in sede di compravendita e locazione **Area (English):** Implementation of Directive 2009/28/EC on the promotion of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Note: the document amending the rule to the obligations for energy from renewable sources coverage (Art. 11 and Annex 3) and for energy certification at the time of the sale and leasing.

Code: Direttiva 2010/31/UE **Title:** la direttiva aggiorna e integra i contenuti della Direttiva 2002/91/CE (che viene abrogata con effetto dal 1 febbraio 2012) obbligando gli Stati membri ad aggiornare i propri recepimenti nazionali **Area (English):** Directive 2010/31/EU on the energy performance of buildings. The Directive updates and integrates the content of Directive 2002/91 / EC (that is repealed with effect from 1 February 2012) requiring Member States to update their national laws.

Code: D.M. 26 giugno 2009 **Title:** Linee guida nazionali per la certificazione energetica degli edifici **Area (English):** National guidelines for energy certification of buildings

Code: D.P.R. 2 aprile 2009, n. 59 **Title:** Regolamento di attuazione dell'art. 4, comma 1, lettere a) e b), del decreto legislativo 19 agosto 2005, n°192, concernente attuazione della direttiva 2002/91/CE sul rendimento energetico in edilizia **Area (English):** Implementing regulation of the article 4,paragraph 1, letters a) and b) of Legislative Decree 19 August 2005, n. 192, concerning implementation of Directive 2002/91 / EC on energy efficiency in building.

Code: D.Lgs. 115/2008 **Title:** Attuazione della direttiva europea 2006/32/CE **Area (English):** Implementation of Directive 2006/32 / EC on energy end-use efficiency and energy services and repealing Council Directive 93/76 / EEC.

Code: D. Lgs. 311/06 **Title:** disposizioni correttive ed integrative al D.Lgs. 192/05 **Area (English):** Corrective and supplementary provisions to Legislative Decree 19 August 2005, n. 192, implementing Directive 2002/91 / EC on the energy performance of buildings.

Code: D.Lgs. 192/05 **Title:** attuazione della direttiva europea 2002/91/CE **Area (English):** Implementation of Directive 2002/91 / EC on the energy performance of buildings.

Code: D.P.R. 26 agosto 1993, n°412 **Title:** regolamento di attuazione della legge 10/91 e norme UNI collegate **Area (English):** Regulation laying down standards for the design, installation, operation and maintenance of heating systems in buildings in order to limit energy consumption, implementing art. 4, paragraph 4, of Law 9 January 1991, n. 10.

Code: Legge 9 gennaio 1991, n°10 **Title:** Norme per il contenimento del consumo energetico per usi termici in edilizia **Area (English):** Rules for the Implementation of the National Energy Plan as regards the national energy use, energy saving and development of renewable sources of energy.

Code: UNI 10339:1995 **Title:** Impianti aeraulici ai fini di benessere. Generalità classificazione e requisiti. Regole per la richiesta d'offerta, le offerte, l'ordine e la fornitura **Area (English):** Aeraulic systems for the purpose of wellness. Overview, classification and requirements. Rules for this inquiry, the offer, the order and delivery.

Code: UNI 10349-1:2016 **Title:** Riscaldamento e raffrescamento degli edifici - Dati climatici - Parte 1: Medie mensili per la valutazione della prestazione termo-energetica dell'edificio e metodi per ripartire l'irradianza solare nella frazione diretta e diffusa e per calcolare l'irradianza solare su di una superficie inclinata **Area (English):** Heating and cooling of buildings - Climatic data - Part 1: Monthly averages for the evaluation of thermal-energy performance of the building and down the methods for the direct solar irradiance and diffuse fraction and to calculate the solar irradiance on an inclined surface.

Code: UNI/TR 10349-2:2016 **Title:** Riscaldamento e raffrescamento degli edifici - Dati climatici - Parte 2: Dati di progetto **Area (English):** Heating and cooling of buildings - Climatic data - Part 2: Design data.

Code: UNI 10349-3:2016 **Title:** Riscaldamento e raffrescamento degli edifici - Dati climatici - Parte 3: Differenze di temperatura cumulate (gradi giorno) ed altri indici sintetici **Area (English):** Heating and cooling of buildings - Climatic data - Part 3: Accumulated temperature differences (degree-days) and other synthetic indices.

Code: UNI EN 12831: 2006 **Title:** Impianti di riscaldamento negli edifici - Metodo di calcolo del carico termico di progetto **Area (English):** Heating systems in buildings - the design heat load calculation method.

Code: UNI EN ISO 6946:2008 **Title:** Componenti ed elementi per edilizia - Resistenza termica e trasmittanza termica - Metodo di calcolo **Area (English):** Components and building elements - Thermal resistance and thermal transmittance - Calculation method.

Code: UNI EN ISO 13370: 2008 **Title:** Prestazione termica degli edifici - Trasferimento di calore attraverso il terreno - Metodi di calcolo **Area (English):** Thermal performance of buildings - Heat transfer via the ground - Calculation methods.

Code: UNI EN ISO 14683: 2008 **Title:** Ponti termici in edilizia - Coefficiente di trasmissione termica lineica - Metodi semplificati e valori di riferimento **Area (English):** Thermal bridges in building - Heat transfer coefficient per unit length - Simplified methods and reference values.

Code: UNI EN 13789: 2008 **Title:** Prestazione termica degli edifici - Coefficienti di trasferimento del calore per trasmissione e ventilazione - Metodo di calcolo **Area (English):** Thermal performance of buildings - coefficients of transmission and ventilation heat transfer - Calculation method.

Code: UNI EN 13788:2013 **Title:** Prestazione igrotermica dei componenti e degli elementi per l'edilizia. Temperatura superficiale interna per evitare l'umidità superficiale critica e la condensazione interstiziale. Metodo di calcolo **Area (English):** Hygrothermal performance of building components and for building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods.

Code: UNI EN ISO 10077-1:2007 **Title:** Prestazione termica di finestre, porte e chiusure oscuranti - Calcolo della trasmittanza termica - Parte 1: Generalità **Area (English):** Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: General.

Code: UNI EN ISO 10077-2:2012 **Title:** Prestazione termica di finestre, porte e chiusure - Calcolo della trasmittanza termica - Parte 2: Metodo numerico per i telai **Area (English):** Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 2: Numerical method for frames.
Code: UNI 10351:2015 **Title:** Materiali e prodotti per edilizia - Proprietà termoigrometriche - Procedura per la scelta dei valori di progetto **Area (English):** Building materials and products - hygrothermal properties - Procedure for selection of design values.
Code: UNI 10355:1994 **Title:** Murature e solai. Valori della resistenza termica e metodo di calcolo. **Area (English):** Walls and floors. Values of thermal resistance and method of calculation.
Code: UNI 10779:2014 **Title:** Impianti di estinzione incendi - Reti di idranti - Progettazione, installazione ed esercizio **Area (English):** Fire-extinguishing systems - hydrant networks - design, installation and operation.
Code: UNI 12845:2015 **Title:** Installazioni fisse antincendio - Sistemi automatici a sprinkler - Progettazione, installazione e manutenzione **Area (English):** Fixed firefighting systems - Automatic sprinkler systems - Design, installation and maintenance.
Code: UNI 9795:2013 **Title:** Sistemi fissi automatici di rivelazione e di segnalazione allarme d'incendio - Progettazione, installazione ed esercizio **Area (English):** Automatic fixed systems of detection and fire alarm signal - Design, installation and operation.
Code: D.M. 22 gennaio 2008, n°37 **Title:** Regolamento concernente l'attuazione dell'articolo 11-quaterdecies, comma 13, lettera a) della legge n. 248 del 2005, recante riordino delle disposizioni in materia di attività di installazione degli impianti all'interno degli edifici **Area (English):** Regulation on the implementation of Article 11 quaterdecies, paragraph 13, letter a) of Law no. 248 of 2005 concerning the reorganization of the provisions relating to the installation of systems in buildings.
Code: CEI 11-17(2007) e variante V1 (2011) **Title:** Impianti di produzione, trasmissione e distribuzione pubblica di energia elettrica - Linee in cavo **Area (English):** Production facilities, public transmission and distribution of electricity - Cable lines.
Code: CEI 64-8 (2012) **Title:** Impianti elettrici utilizzatori a tensione nominale non superiore a 1.000 V in corrente alternata e a 1.500 V in corrente continua **Area (English):** Electrical systems using a nominal voltage not exceeding 1.000 V AC and 1.500 V DC.
Code: CEI 0-16 (2014) **Title:** Regola tecnica di riferimento per la connessione di Utenti attivi e passivi alle reti AT ed MT delle imprese distributrici di energia elettrica **Area (English):** Reference technical rules for the connection of active and passive Users to HV and MV networks of distributors of electricity.
Code: CEI 99-2 (2011) **Title:** Impianti elettrici con tensione superiore a 1 kV in corrente alternata. Parte 1: Prescrizioni comuni **Area (English):** Electrical installations with voltage exceeding 1 kV AC. Part 1: Common requirements.
Code: CEI 99-3 (2011) **Title:** Messa a terra degli impianti elettrici a tensione superiore a 1 kV in corrente alternata. **Area (English):** Earthing of electrical installations in voltage exceeding 1 kV AC.
Code: CEI EN 61439-1 e CEI EN 61439-2 (2012) **Title:** Apparecchiature assiemate di protezione e di manovra per bassa tensione (quadri BT) - Parte 1: Regole generali e Parte 2: Quadri di potenza. **Area (English):** Assemblies and protection for low-voltage switching (BT boards) - Part 1: General requirements and Part 2: Power Panels.
Code: CEI EN 62305 (serie) **Title:** Norme per la protezione contro le scariche atmosferiche **Area (English):** Standards for the protection against atmospheric discharges.
Code: Legge 1 marzo 1968, n. 186 **Title:** Disposizioni concernenti la produzione di materiali, apparecchiature, macchinari, installazione e impianti elettrici ed elettronici. **Area (English):** Provisions concerning the production of materials, equipment, machinery, installations and electrical and electronic systems.
Code: Legge 8 ottobre 1977, n. 791 **Title:** Attuazione della direttiva del consiglio delle Comunità europee (n. 73/23/CEE) relativa alle garanzie di sicurezza che devono possedere il materiale elettrico destinato ad essere utilizzato entro taluni limiti di tensione. **Area (English):** Implementation of Council Directive of the European Communities (n. 73/23 / EEC) on safety guarantees that must possess the electrical equipment designed for use within certain voltage limits.
Code: D.Lgs. 25 novembre 1996, n. 626 **Title:** Attuazione della direttiva 93/68/CEE in materia di marcatura CE del materiale elettrico destinato ad essere utilizzato entro taluni limiti di tensione. **Area (English):** Implementation of Directive 93/68 / EEC on CE marking of electrical equipment designed for use within certain voltage limits.
Code: D.Lgs. 31 Luglio 1997, n. 277 **Title:** Modificazioni al decreto legislativo 25 novembre 1996, n. 626, recante attuazione della direttiva 93/68/CEE in materia di marcatura CE del materiale elettrico destinato ad essere utilizzato entro taluni limiti di tensione **Area (English):** Modifications to the legislative decree 25 November 1996 n. 626, implementing Directive 93/68 / EEC regarding CE marking of electrical equipment designed for use within certain voltage limits.
Code: Legge 22 febbraio 2001, n. 36 **Title:** Legge quadro sulla protezione dalle esposizioni a campi elettrici, magnetici ed elettromagnetici **Area (English):** Framework law on protection from exposure to electric, magnetic and electromagnetic fields.

Code: D.P.C.M. 8 luglio 2003 **Title:** Fissazione dei limiti di esposizione, dei valori di attenzione e degli obiettivi di qualità per la protezione della popolazione dalle esposizioni ai campi elettrici e magnetici alla frequenza di rete (50 Hz) generati dagli elettrodotti **Area (English):** Establishment of exposure limits, attention and quality targets for the protection of the population against exposure to electric and magnetic fields at the mains frequency (50 Hz) generated by power lines.

Code: Legge 23 agosto 2004, n. 239 **Title:** Riordino del settore energetico, nonché delega al Governo per il riassetto delle disposizioni vigenti in materia di energia **Area (English):** Reform of the energy sector and delegation to the government to reform the current rules on energy.

Code: D.Lgs. 6 novembre 2007, n. 194 **Title:** Attuazione della direttiva 2004/108/CE concernente il riavvicinamento delle legislazioni degli Stati membri relative alla compatibilita' elettromagnetica e che abroga la direttiva 89/336/CEE **Area (English):** Implementation of Directive 2004/108 / EC on the approximation of the Member States relating to electromagnetic compatibility and repealing Directive 89/336 / EEC.

Code: DM 29/05/08 **Title:** Approvazione della metodologia di calcolo per la determinazione delle fasce di rispetto per gli elettrodotti **Area (English):** Approval of the calculation methodology for the determination of buffer zones for power lines.