SUSTAINABLE BUILT ENVIRONMENT: TRANSITION ZERO

THE UTRECHT SBE16 CONFERENCE ON 7-8 APRIL 2016

CONFERENCE PUBLICATION

Ivo Opstelten, Ronald Rovers, Nadia Verdeyen & Andy Wagenaar (eds.)

SMART SUSTAINABLE CITIES

SUSTAINABLE BUILT ENVIRONMENT: TRANSITION ZERO

CONFERENCE PUBLICATION

OF THE UTRECHT SBE16 CONFERENCE

ON 7-8 APRIL 2016

IVO OPSTELTEN, RONALD ROVERS,

NADIA VERDEYEN & ANDY WAGENAAR (EDS.)

ORGANIZED BY

EMPOWERD BY

COLOPHON

TITLE
INSITER self-inspection
method and instruments
to ensure optimal
performance of prefab
retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

INSITER SELF-INSPECTION METHOD AND INSTRUMENTS TO ENSURE OPTIMAL PERFORMANCE OF PREFAB RETROFITTING SOLUTIONS

The benefits of prefab retrofitting solutions for NET Zero Energy buildings (such as prefab components for building envelopes, windows, equipment) are at risk because of bad implementation during the construction processes. As a result, the energy-efficiency potential as designed will not be realised. The European Horizon 2020 research project INSITER develops a quality assurance method that closes the performance gap between design and construction.
This paper reports on the first phase of such a method, being a desk research to identify the most frequent construction errors, state-of-the-art diagnostic instruments to detect the errors and suitable standards for performance control.

1 Introduction

The EU authorities have set ambitious targets to reduce CO_2 emissions to 20% below their 1990 levels (CEC, 2007). The building sector is the largest energy user in Europe, consuming 39.8% of the total energy in the EU-27 (European Union, 2012). Therefore it is an important sector to focus on, regarding its large reduction potential. With the revised 2010 Energy Performance of Buildings Directive (EPBD) and the 2012 Energy Efficiency Directive (EED), the European Commission has laid down a new set of energy efficiency standards, therewith improving the energy performance of buildings in all EU Member States, both new built and existing ones.
To reach the EU CO_2 emission reduction targets and meet the energy efficiency standards, the European Commission supports innovation in energy saving in construction, among others by research grants. The INSITER project was funded under the Horizon 2020 research program.

1.1 The INSITER project
INSITER is a research project that runs from November 2014 till October 2018. The project aims to eliminate the gaps in quality and energy-performance between design and realization of energy-efficient buildings based on prefab components.

TITLE
INSITER self-inspection method and instruments to ensure optimal performance of prefab retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

34

During construction, each actor of the highly fragmented value-chain (Egan, 1998), must ensure that his contribution fits into a quality framework defined collectively at the design level. However, the targeted performance aimed at during all stages of the design process are hampered by critical shortcomings during on-site construction and refurbishment that cause a lower built-quality and sub-optimal energy-saving in the building lifecycle. Through self-inspection techniques, based on intuitive and cost-effective Augmented Reality (AR), INSITER aims to leverage the energy-efficiency potentials of buildings based on prefab components, not only NET Zero Energy buildings but also other types of buildings, as well as refurbishment and maintenance projects. It will scale-up the use of BIM for standardised inspection and commissioning protocols, involving all actors in the value-chain.

In short, the activities in the project focus on developing (Sebastian et al., 2015):

- a method for self-inspection, containing an explanation of which construction workers should carry out what activities for quality control at which moment during the construction works;

- hardware tools that can be used for self-inspection, such as laser scanners for the correct positioning of building elements. INSITER aims to resolve the current limitations of existing technologies that are constrained by the need for continuous updates and relatively low speed and accuracy of the data acquisition.

- software that allows the previously mentioned self-inspection tools to communicate with each other by means of a smart Application Programming Interface (API) and data integration with a cloud-based Building Information Model (BIM).

- a Building Information Model for lifecycle performance and asset management of energy-efficient buildings while connecting a virtual model and the physical building in real-time.

The research outcomes of the above named activities will be validated and demonstrated in real-time use cases.

By the end of the project, INSITER should be able to verify the estimated energy performance based on the design prior to construction and be able to anticipate, prevent and resolve performance and quality gaps. Construction workers, supervisors,

Theme 1 Upscaling

TITLE
INSITER self-inspection method and instruments to ensure optimal performance of prefab retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

35

clients and end-users should be provided with practical method and training to perform self-instruction & self-inspection and a set of intuitive, robust and cost-effective measurement instruments with BIM & AR to perform self-instruction & self-inspection should be developed.
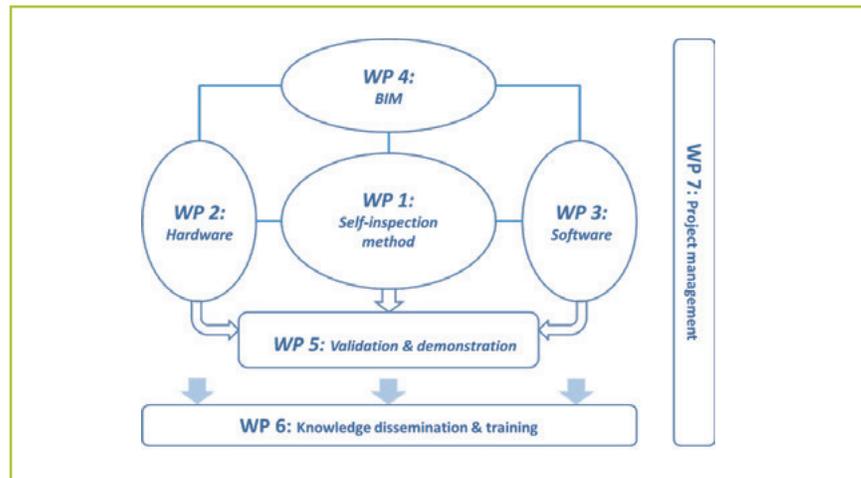
Figure 1: INSITER project structure (Source: Sebastian et al., 2015)

2 Methodology

A desk research was carried out to identify the most frequent construction errors and to find suitable standards for performance control of the construction process and the finalized building components that can be taken as a reference for the development of the INSITER self-inspection method. In this paper the errors and standards are solely listed, because it reports on the data acquisition which has taken place. Further developments and the relationships between errors and standards will be elaborated in upcoming papers.

The review on the construction errors was done by experts from four companies of the consortium that are dealing on a day-to-day basis with construction projects, being an engineering firm from Italy, architect's offices from Germany and Italy (all SMEs); and a Spanish construction company (Large Industry). The review resulted in a list of 96 errors, which after deliberation among the consortium experts was reduced to 12 crucial errors for the building quality and energy performance of the building envelope (Di Giulio et al., 2015).

TITLE
INSITER self-inspection
method and instruments
to ensure optimal
performance of prefab
retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

The collection of the standards was a joint effort of in total ten partners from the Netherlands (4), Italy (3), Spain (2) and Germany (1). In total 76 standards were found relevant for self-inspection, of which few were selected for further analysis because they fit best to the INSITER objectives related to self-inspection of prefabricated building components.

3 Results

3.1 Construction errors

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 technical drawings and specifications elaborated by the design team.

- Poor manufacturing of the building components. The incorrect technical manufacturing of the envelope building components can cause defective components characterised by technical attributes differing from the expected performances.

- 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.

- Assembly of damaged 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.).

- 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.

TITLE
INSITER self-inspection
method and instruments
to ensure optimal
performance of prefab
retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

37

- Poor component locations or improper installation. A correct installation of building components is extremely significant in order to maintain the expected performance of the construction.

- Misinterpretation or incorrect use of the documentation (e.g. technical drawings). The technical knowledge background of the construction workers and the understanding of the final design elaborated by the design team are very important for the correct realisation of the building.

- 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) will alter the energy performance of the building.

- Geometric problems of the building components. To seal the building envelope it is necessary that all building components are properly realised from the geometric point of view.

- Installation of unsuitable material. The monitoring of the component quality that arrives on-site is very important to preserve the original requirements.

Theme 1 Upscaling

TITLE
INSITER self-inspection method and instruments to ensure optimal performance of prefab retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

38

- Windows and doors incorrectly sealed on-site. The correct assembling of windows and doors on external walls as well as skylights in roofs is crucial to reduce the airflow.

- Irregular site inspection by the project manager. Regular inspection on the building construction site by the project manager is fundamental to control the realisation of the building quality.

3.3 Condition assessment and inspection standards for building components
This section lists and gives a short explanation of the standards most relevant for the INSITER objectives:

- NEN 2767-1:2011/C1:2013 NL - Condition assessment - Part 1: Methodology and Part 2: Lists of faults describes a method to establish the technical quality of building and installation components univocally. Relevant for INSITER:
  - The building is logically subdivided in components
  - Classification of the importance of the defects
  - Classification system for severity of defects in condition
  - 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 sets generic rules for dimensional control of building elements, positioning on-site of building elements, spaces and joints. Relevant for INSITER:
  - Instructions on positioning of measurement points
  - Instructions on registration of measurements
  - Instructions on operation of tools
  - Definitions of deviations

- UNE 85247-11 Windows and doors. Watertightness. Site test defines the method to use in order to identify water penetration points in windows and doors once installed in a building. Relevant for INSITER:
  - Instructions on Initial assessment
  - Instructions on positioning of measurement points
  - Instructions on registration of measurements

Theme 1 Upscaling

TITLE	AUTHORS	ORGANIZATION	MAIL ADDRESS
INSITER self-inspection method and instruments to ensure optimal performance of prefab retrofitting solutions	Dr Martin Roders MSc Dr Arch Emanuele Piaia Dr Rizal Sebastian MSc	DEMO Consultants Delft, the Netherlands Ipostudio Architetti SRL Florence, Italy DEMO Consultants Delft, the Netherlands	martin@demobv.nl +31 6 10436652

- DIN 18197, April 2011 - Sealing of joints in concrete with water stops applies to planning, assessment, treatment, processing and installation of water stops used for sealing against ground moisture, non-pressing or pressing water as well as the termination of joints. Relevant for INSITER:
  - Instructions on positioning of measurement points
  - Instructions on installation of measurement points
  - Instructions on monitoring and documentation
  - Instruction on 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 is a tool to inspect existing building uniformly on the aspect of fire safety. Relevant 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 and 2: List of general terms 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. Relevant 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-EN-13187 Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method specifies a qualitative method, by thermographic examination, for detecting thermal irregularities in building envelopes. Relevant 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

Theme 1 Upscaling

TITLE
INSITER self-inspection
method and instruments
to ensure optimal
performance of prefab
retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

40

The analysis of the condition assessment and inspection standards has led to the following key elements that should be taken up in the INSITER inspection protocols and guidelines:

- A clear definition of the building components and key data to be assessed (window, or façade element etc.)

- Common vocabulary

- Description of the diagnostic instrument per inspection item

- Instructions on the operation of diagnostic instruments

- Instructions on the positioning (and installation) of measurement points

- Instructions on how to register and report the measurements

- Description of how and by whom measurements are interpreted: software based, e.g. clash detections, or with support of (trained) inspectors

4 Discussion

As a part of a larger research project, this paper has identified frequent construction errors in prefab construction, as well as the relevant condition assessment methods that can be used for the prevention of the errors. In the next phases of the research the quantitative boundaries shall be defined that indicate to which extent an imperfection resulting from the production process unacceptably compromises building quality or energy performance. In other words, it will be defined when an error results in unacceptable consequences, because in that case it needs to be corrected. For example, if a joint between two building components is not completely closed (construction error), this does not necessarily mean that it leaks air, or that it leads to such a loss of energy performance that it justifies rework (implying higher costs etc.).

The follow-up research shall establish the width of the joint that leads to unacceptable loss of performance. In the above example, it could be that every joint >2cm is considered an error, <2cm is no error.
Moreover, a Stakeholder Analysis shall be carried out, to determine which actor is responsible for deciding on the tolerance boundaries. For example, the engineer responsible for the energy calculations can indicate when unacceptable heat loss occurs, while an architect focuses on the aesthetical and functional performance of the building.

Theme 1 Upscaling

TITLE
INSITER self-inspection method and instruments to ensure optimal performance of prefab retrofitting solutions

AUTHORS
Dr Martin Roders MSc

Dr Arch Emanuele Piaia

Dr Rizal Sebastian MSc

ORGANIZATION
DEMO Consultants
Delft, the Netherlands
Ipostudio Architetti SRL
Florence, Italy
DEMO Consultants
Delft, the Netherlands

MAIL ADDRESS
martin@demobv.nl
+31 6 10436652

41

In the research stages thereafter, it shall be defined who will detect the error in the most efficient way and at which moment during the construction process by means of self-inspection. The outcomes of these stages will be implementation guidelines. In the meantime the development of INSITER diagnostic instruments, software and BIM takes place so that the persons in the field are able to measure if the error is really an error. Taken again the example of the joint between two building components, the tools need to be able to measure the distance (in cm) between the components, so that it can be verified whether the components are placed correctly (joint <2cm) or not (joint >2cm).

Regarding the bigger picture of the whole project, developments are made at hardware level, the tools that will be used to measure and detect errors; at software level, to make the hardware tools communicate with each other and produce information for decision support and at BIM level to be able to monitor the real-time progress and quality with the simulated progress and quality.

5 Conclusion

Self-inspection will not disrupt on-site working processes by additional effort; it will save time and costs by making the processes efficient and accurate. The INSITER methodology supported by the relevant measurement and diagnostic instruments will close the gap between design and realisation in new construction, refurbishment and maintenance projects. The real-time INSITER self-inspection concept has a strong contrast with the traditional approach of 'post-inspection'. These are currently done by an observer/auditor/controller after a working process is finished. In such a traditional approach, errors and defects are always discovered 'just too late', followed by a long and difficult process to point out 'who to blame' and to decide 'how to fix the mistakes done'. INSITER will prevent costly repair actions and make the process transparent regarding liability, accountability and insurance.

ACKNOWLEDGEMENTS

References

Commission of the European Communities, 2007. Communication from the Commission to the Council, the European Parliament, the European economic and social committee and the committee of the regions, COM(2007) 2 final, Brussels.

Theme 1 Upscaling

TITLE	AUTHORS	ORGANIZATION	MAIL ADDRESS
INSITER self-inspection method and instruments to ensure optimal performance of prefab retrofitting solutions	Dr Martin Roders MSc Dr Arch Emanuele Piaia Dr Rizal Sebastian MSc	DEMO Consultants Delft, the Netherlands Ipostudio Architetti SRL Florence, Italy DEMO Consultants Delft, the Netherlands	martin@demobv.nl +31 6 10436652

42

Di Giulio, R. et al., 2015. INSITER: Best practices and existing shortcomings. *Deliverable report 1.1*. Florence, Italy

Egan, J., 1998. Rethinking construction: *The report of the Construction Task Force.* DETR, London.

European Union, 2012. EU energy in figures. *Statistical pocketbook 2012*, Publications Office of the European Union, Luxembourg.

Sebastian, R. et al., 2015. Intuitive Self-Inspection Techniques based on BIM for Energy-efficient Buildings: EU Horizon 2020 Research Project INSITER. Presented at the Eighth International Conference on Construction in the 21st Century (CITC-VIII) *"Changing the Field: Recent Developments for Future Engineering and Construction"*, May 27-30, 2015, Thessaloniki.