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Built2Spec project: Tools for Self-Inspection and Quality checks – towards 21st Century Construction Worksite

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Abstract

Built2Spec (B2S) is an Horizon 2020 EU-funded project in the Energy Efficiency in Buildings domain that seeks to eliminate the gap between a building's designed and as-built performance. To reach this goal B2S brings together a new and breakthrough set of technological advances for worksite and self-inspection / quality assurance that will be put into the hands of construction stakeholders since the begin of construction process. B2S will expand upon a cloud based construction support platform. New self-inspection technologies managed within the platform and developed in the project regard: rapid BIM modelling via instant 3D capture with smartphones; environmetal and structural smart embedded sensors; special IR camera in smartphones; portable device for Indoor Air Quality (IAQ) tests; portable low pressure air tightness device; lightweight portable sound source. The final B2S challenge is to develop products and services to provide EU leadership in the field of worksite self-inspection, compliance and quality checks.

Keywords - energy efficiency quality checks; regulation compliance; management platform; portable devices; IR thermal; BIM; low pressure air tightness; IAQ

1. Introduction

In buildings and infrastructures construction processes it is well documented that a clear gap exists in the availability of structured and systematic mechanisms to support the decision-making, execution and commissioning phases of construction processes ([1]). This can result in defects that degrade:

- the intended energy and comfort performance of new structures and retrofits;
- the trust and confidence in the implementation of the potentially higher-cost sustainable design, construction and retrofit actions Europe needs to meet its sustainability targets.

Indeed, expected energy performance can be seriously compromised if the construction sector keeps moving almost exclusively within the boundaries of traditional expertise and know how. World-class techniques for self-inspection and quality check measures are coming out of Europe's universities and RTO organizations. Portable and user-friendly low cost solutions are coming out of Europe's industrials. Put together these techs and combining them into proper business models, will provide the opportunity to change behavior at EU construction worksites for the EU construction industry. In B2S, this value chain from research (technologies and techniques) to market is assembled and integrated within a holistic, systematic, collaborative and standards based approach and finally brought to worksite construction workers via a BIM-enabled Virtual Construction Management Platform (VCMP) and environment. B2S macro level objectives are:

- to realize at the worksite self-inspection techniques in the areas of thermal, energy, airtightness, indoor air quality and acoustic performance;
- use/develop mobile devices to revolutionize construction practices of the 21st century by bringing them to the worksite;
- link data between "worksite and office" within an integrated collaborative design and construction management framework via a Virtual Construction Management Platform.
- reduce the administrative burden on workers, inspectors and managers alike by automating data capture, inspection steps, and quality check measures with smart devices, intelligent surveys and data analytics.

2. Built2Spec Tools

To eliminate the gap between a building's designed and as-built performance different tool, technologies and procedure (e.g. quality check template for compliance) will be developed within B2S. All the process will be integrated and managed by the VCMP to allow all the Users to conduct, share and visualize in all moment the documents the self-inspections to be carried out on worksite.

In all these approaches the common thread in B2S is to provide "**portable**" and "**user-friendly**" solutions in order to be easily applied on worksite for self-inspection and quality checks during standard working activities also by untrained persons without particular skills in energetic/structural field.

More in detail the tools in development are:

- **Standoff U-values Assessment**

In many European countries, thermal regulations for energy efficiency assessment of new building generation and refurbished ones require now more efficient and robust thermal diagnostic tools ([2]). Diagnostic tools should take into account not only the thermal insulation characteristics but also the building thermal inertia. In current applications most of the time the information from thermal infrared measurements in a built environment are interpreted qualitatively. This can be observed in any operational project related to thermal diagnosis of buildings. Researchers recently developed tools that allows to identify U-values from measured temperatures using reverse modelling approaches ([3]-[5]). In B2S, the reverse models will be adapted and validated in the context of the building construction sector and customized to work with inputs from mobile thermal infrared (TIR) devices. These TIR data will serve both for the identification of the surfaces and for the computation of U-values. Each aspect will be developed and then integrated into the VCMP for self- and user-friendly inspections (Fig 1).

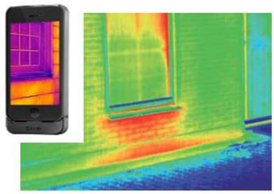

Fig 1 Standoff U-values Assessment – thermal imaging

- **Low Pressure Air Pulse Air Tightness devices**

European Directive 2010/31/EU requires the energy performance of buildings to be calculated in all member states. Many countries have minimum airtightness requirements, such as a maximum air permeability of 10 $m^3/h \times m^2$ at 50Pa in the UK (ODPM, 2010). The globally adopted standard for measuring airtightness is the "blower door technique" (ISO 9972:2006, EN 13829:2000). It can only produce accurate results at pressures much higher and unrepresentative of those found typically in infiltration. Extrapolating the results at high pressures (typically 50 Pa) down to infiltration pressures (typically 4 Pa) has been shown, as summarized in the ASHRAE Fundamentals Handbook (2014), to incur significant uncertainty (up to +/- 40%). It is also time consuming to set up and carry out, costly, and requires bulky equipment. Furthermore it needs for trained technicians and rarely used for remediation purposes until the final commissioning stages. The Air Pulse technique and device in development in B2S aims to avoid the above issues proposing a portable and user-friendly device integrated with the VCMP for quick, cheaper and repeatable test on site also by untrained workers (Fig 2). The key features of this device/approach are: (i) the measurement of the pressure difference a short time before and after the 1.5 sec. pulse allowing wind and buoyancy effects to be largely eliminated; (ii) the shape and duration of the pulse such that a period of quasi-steady flow is obtained eliminating inertia effects (iii) minimal variation of pressure during the quasi-steady period, such that envelope flexing is not a problem The technique has been proven to work well for a variety of building sizes, ages, construction types and airtightness levels in both calm and adverse wind conditions.

Fig 2 Device for air-pulse test in development

- **3D model acquisition and Imagery Techniques**

Accurate and efficient monitoring of building during construction is an important issue to support fundamental activities such as progress tracking, construction control decision making, and construction dimensional quality control. Current monitoring techniques are principle based on manual measurements; time and labor demanding and therefore too expensive and unreliable to be comprehensively applied on sites. Past research in this area had proposed different techniques to automate this process. In the former case, a direct 3D to 3D comparison is performed between the point cloud captured by the scanner on site and the BIM model of the building. A semi-automatic technique is then deployed to detect what is congruent and what is not with the BIM model. In B2S image-based technique to detect geometric inconsistencies between the captured images and a model will be developed. In the focus will regard the development /calibration of semantic algorithm. This approach will be then applied at micro level using simple devices such as mobile scan (for detailed checks – e.g. rebars diameters; columns verticality,…), and macro level (at site level – e.g. to check construction progress; i.e. 4D comparison with 4DBIM) using UAVs (i.e. drones). Each aspect will be developed and then integrated into the VCMP for self- and user-friendly check/comparison with BIM model (Fig 3).

Fig 3 3D reconstruction – drone in action ([6])

- **Acoustic testing**

Acoustic testing currently involves an expensive and hardly portable set of equipment described in the European regulation ISO 16283. In order to minimize cost and to make this technology more portable and automate its use, the capabilities of new smartphones as acoustic receivers can be explored and testing sound insulation in buildings is a promising application field. When dealing with airborne sound insulation in buildings, ISO 16283 and ISO 140-5 are the standards to follow. In this case, the sound pressure level must be measured with class 0 or class 1 microphones and the loudspeaker should give enough noise level from 100 Hz to 3150 Hz octave band with a maximum of 5 dB between bands. To be able to perform these acoustic measurements expensive equipment is needed, as well as a good technical background to be able to obtain the sound insulation indexes properly. To overcome this cost, there is a way to predict the sound insulation performance of a building using the UNE EN 12354 series ([7]). However, the difficulty to collect the dataset for calculating, and evaluating the uncertainty of the prediction model, provides a low accuracy and reliability. An alternative low-cost method to perform acoustical measurements in situ would overcome these drawbacks. In this sense to minimize costs and to make these technologies more portable and user-friendly the capabilities of smartphones as acoustic receivers will be explored ([8] - [12]). The aim is to develop a novel lightweight sound source for acoustic testing that provides a more diffuse field than standard loudspeakers and ensures easy portability and regulation compliance. An indoor positioning method is being developed to tag the location of the acoustic measurements. This is based on Bluetooth Low Energy beacons. This novel methodology will reduce the cost of experimental tests and be more suitable for self-inspection(Fig 4). All these aspects will be integrated into the VCMP.

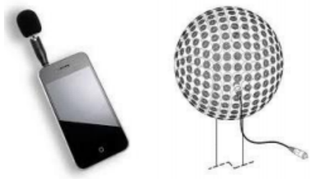

Fig 4 New acoustic devices and procedures in development

- **Sensor-embedded Construction Elements**

People spend approximately 90% of their lives indoors ([13]). Thus, it is very important to maintain safe, healthy and comfortable conditions in buildings. Knowledge about the transport of various phenomena through multi-layered building components is vital in evaluating the components' structural and environmental performance. The performance of building materials should be monitored in order to ensure the quality of building construction and compliance with existing standards and regulations ([14]). Smart building materials are sensor-embedded construction elements for continuous self-inspection and quality checks. The intent of B2S is to embed these environmental/structural sensors at the precast manufacturing stage and at the on-site construction stage (Fig 5). The continuous monitoring and inspection of the data will allow strength gain and environmental performance of concrete to be continuously monitored and compared with design intent/standards/guidelines, as well as determining any long term effects, such as creep. Following this, measured data will be analysed and used to develop calibrated numerical models that predict building environmental and structural performance. The measurements will include concrete temperature, moisture, strains, pH, chloride ion and early signs of reinforcement corrosion, all critical data for evaluating precast/in situ system performance ([15] - [17]). The performance criteria for data measurement will act as input requirements to the integrated VCMP.

Fig 5 Example of smart-embedded building sensor

- **Indoor Air Quality (IAQ)**

Current construction guidelines, procedures and standards for residential buildings usually do not focus much on IAQ or better inadequate for specifying materials and designing ventilation systems to ensure a healthful indoor environment - except in special cases like as an example LEED and BREEAM. In contrast the rapid introduction of new building construction materials and commercial products and inhabitants' awareness, pose challenges to systems integration in the whole building construction process from the design until the commissioning and "in-use" phase ([18]). As observed in [19] the choice of building materials strongly influence IAQ (e.g. sources of VOCs and formaldehyde). Particularly, the specific construction procedures implemented can have a major impact on IAQ in the building. Furthermore standard approaches require time consuming and high cost laboratory tests. Thus there is a real need to know in near-real time, anticipate and control emissions from building materials used to control thereafter the quality of the air inside the building in all construction phases in site. The ambition in B2S is to develop a truly portable device for in near-real time measurement of the pollution to be used by non-specialists, and simplified integrated IAQ indicator(s) for the end-user interface based on current knowledge, regulatory limits and health risks (Fig 6). All these aspects will be integrated into the VCMP.

Fig 6 IAQ analyzer device in development

- **Building Information Modelling (BIM)**

BIM is often perceived as the "holy grail" for construction practice. In a fragmented industry of conflicting interests, proprietary file formats and misunderstanding using IM can still lead to data loss and frustration (Fig 7). However, the potential of using open standards and complementary BIM-tools in collaborative design is increasingly being realized. Stretching the potential of BIM to the construction site and beyond is one of the B2S objective. In B2S will be used the BIM information to check whether the as-built situation complies with the designed – not just after the project is delivered but also during the construction process. Relevant information from the BIM will be made available on-site through the VCMP. These information will be compared to what the user can see, measure and test with the other technologies in development. Open BIM-dataformat IFC and the BIMserver platform will be adopeted as the basis to develop interfaces with various other data formats (e.g. sensor data, measurement data, images) ([20] - [26]).

Fig 7 Building Information Modelling

3. Conclusions

In this paper the EU funded Project Built2Spec which intents is to eliminate the gap between a building's designed and as-built performance is presented.

An overview of the project and main goals are presented.

This paper is focused on describing the tools and procedures (news self-inspection strategies; quality checks, VCMP,…) will be developed across the life time of the project to cover the existing energy gap between "designed" and "as-built" directly on site during the all construction phases.

The procedures, strategy and tools in developments will guarantee a reduction in term of time, and hence costs, spent for the checks and higher performance of the buildings simply giving the possibility to all Users to check step-by-step, via VCMP, the progress of the works and act immediately when needed to bring back the process to the "right path" as from design stage. Furthermore the integration of all the construction process within the VCMP will guarantee information transparency and data repository for future checks/needs.

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