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METHODOLOGY FOR QUALITY CHECKS FOR ENERGY EFFICIENT BUILDINGS

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Abstract

The built environment accounts for more than 40% of the overall energy consumption and 36% of the overall CO_2 emissions in Europe. Moreover, statistics show that construction and the upkeep of European buildings and infrastructure is the largest industry worldwide accounting for approximately 10% of global GDP. A clear gap exists in the availability of structured and systematic mechanisms to support the decision-making, execution and commissioning phases of construction processes. This can result in defects that degrade the intended energy and comfort performance of new structures and retrofits. Such errors also weaken the trust and confidence in the implementation of the potentially higher-cost sustainable designs, construction and retrofit actions.

This paper presents the overview, objectives and impact of the Built2Spec project, which brings together a new and breakthrough set of technological advances for self-inspection and quality assurance for energy efficient buildings. The project expands upon a cloud based construction support platform, following the most advanced integrated design and delivery framework for the building sector. The platform aims to facilitate worksite activities and quality compliance by putting knowledge in hands of contractors. This is done through shared design specifications and 3D models, installation guidelines, information on regulatory frameworks, and help from construction experts on smartphones and tablets.

Furthermore, this research aims to develop a methodology for the use of sensor-embedded construction elements for continuous self-inspection and quality checks in energy efficient buildings. Those prototype smart building components are designed, tested and linked to models that predict performance and enable continuous product life cycle quality checks.

Keywords:

Energy efficient buildings; Building to specifications; Quality checks; Smart building components

1 INTRODUCTION

Human-induced climate change is occurring globally and has already had a significant impact on the environment and society, due to increased levels of greenhouse gases. It is well documented that the built environment in Europe accounts for more than 40% of the overall energy consumption and 36% of the overall CO_2 emissions [1]. Furthermore, statistics show that construction and the upkeep of buildings and infrastructure is the largest industry worldwide accounting for approximately 10% of global gross domestic product (GDP) [2].

Concerning the problem of increased energy consumption in the building sector, the European Union (EU) adopted the Directive 2010/31/EU [3]. According to the Directive [3], member states are requested to adopt a methodology for calculating the energy performance of buildings (i.e. energy performance certification). The objective of this Directive [3] is to ensure all new buildings are almost zero-energy consumption buildings by the end of 2020. In order to meet the requirements posed by the EU and, thus, reduce the environmental impact of buildings, energy efficient measures must be taken into account when designing new and retrofitting old buildings.

However, there is a clear gap in the availability of structured and systematic mechanisms to support the decision-making, execution and commissioning phases of construction processes [4]. This can result in defects that degrade the intended energy and comfort performance of new structures and retrofits. Furthermore, such errors can also diminish the trust and confidence in the implementation of the potentially higher-cost sustainable designs, which are needed to meet the sustainability targets in Europe's construction and retrofit actions.

This paper presents the overview, objectives and impact of the Built2Spec project [5], which brings together a new and breakthrough set of technological advances for self-inspection and quality assurance for energy efficient buildings. The project expands upon a cloud based construction support platform, following the most advanced integrated design and delivery framework for the building sector. The platform aims to facilitate worksite activities and quality compliance by putting knowledge in hands of contractors. This is done through shared design specifications and 3D models, installation guidelines, information on regulatory frameworks, and help from construction experts on smartphones and tablets.

Furthermore, this paper presents a methodology for the use of sensor-embedded construction elements, i.e. smart building components, developed at the National University of Ireland (NUI) Galway, for continuous performance self-inspection and quality checks in buildings. This innovative system for embedding sensors in building elements, collecting information from the sensors (environmental, structural, RFID) and presenting relevant information in a user-friendly, accessible manner will be extremely valuable to engineers, building managers, contractors and other stakeholders, and will support continuous self-inspection and quality checks to reduce the gap between the designed and actual building performance.

2 BUILT TO SPECIFICATIONS

Built2Spec stands for 'Built to Specifications - Tools for the 21st century construction site' [5]. The project consortium of 20 European partners brings together a new and breakthrough set of technological advances for self-inspection and quality assurance that will be put into the hands of construction stakeholders to help meet EU energy efficiency targets, standards for constructing and retrofitting buildings, and related policy ambitions.

The challenge Built2Spec undertakes is to expand upon a cloud based construction support platform, conceived following the most advanced integrated design and delivery framework for the building sector. The platform will host applications that facilitate worksite activities and quality compliance by putting knowledge in hands of contractors. This will be achieved in the form of shared design specifications and 3D models, installation guidelines, information on regulatory frameworks, and help from construction experts on smartphones and tablets. The Built2Spec platform will be integrated into the operations of small and medium-sized enterprise (SME) contractors, large construction firms, and end user clients directly within the consortium.

The Built2Spec project concept (Figure 1) consists of four successive, correlated and independent 'levels'. The ground breaking technological advances for self-inspections and quality assurance (Level 1) proposed in this work include:

- 3D and imagery tools;
- Building information modelling (BIM);
- Smart building components;
- Energy efficiency quality checks;
- Indoor air quality tools;
- Airtightness test tools with air-pulse checks;
- Thermal imaging tools;
- Acoustic tools.

At Level 2 mapping of required self-inspection techniques takes place. Firstly, the stakeholders, involved in the particular projects, must be defined through methodical interviews, workshops and questionnaires. The stakeholder groups include architects, engineers, construction companies, material suppliers, foreman, worksite men, facility managers, etc. Secondly, current practices for quality inspection processes are mapped for a particular stakeholder (in a specific process / project phase). This can be done through the use case scenarios to determine how the processes could be improved by the Built2Spec technologies. Finally, the ways of automating the quality inspection processes (or their parts) are determined.

At Level 3, the technologies and knowledge of the quality inspection processes are integrated into the Integrated Design and Delivery Solutions (IDDS) framework. IDDS has been developed by academia, industry, governments and clients on five continents in order to create one visionary framework that enables '*the building and construction sector to improve its performances and to enhance its relevance to society in a magnitude greater than from any innovation in building and construction that we have witnessed in the last two or three decades'* [6]. IDDS couples collaborating people, interoperable technologies and integrated processes providing knowledge, lean construction, integrated project delivery, BIM, training and other aspects [6]. By considering and road mapping self-inspection and quality assurance within an IDDS framework, this project (i) provides the opportunity to achieve synergistic benefit from different technologies and techniques and (ii) makes accessible the approach to decision makers, end users and stakeholders at all levels during the building life cycle. This efficient information capture and sharing at all stages of the construction process, with clear and shared objectives for the stakeholders, can dramatically improve quality and cost during building's construction and long term commissioning.

At Level 4, all of the technologies, techniques and processes are connected to a Virtual Construction Management Platform (VCMP) supporting the collection and sharing of all project data, from initial design to delivery.

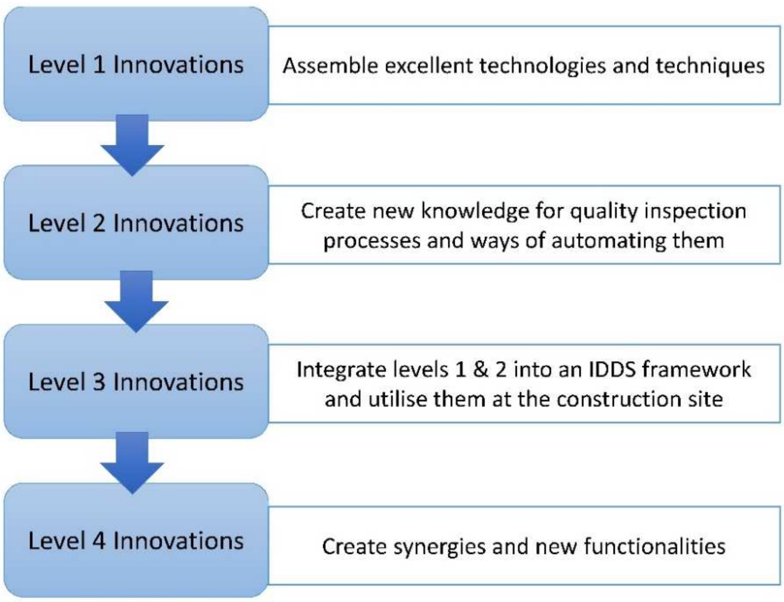

Fig. 1. The project concept.

Over 48 months work program and 10 work packages (Figure 2), Built2Spec integrates various sectors, knowledge and skills in order to achieve project's main goal of supporting continuous self-inspection and quality checks to reduce the gap between the designed and actual building performance.

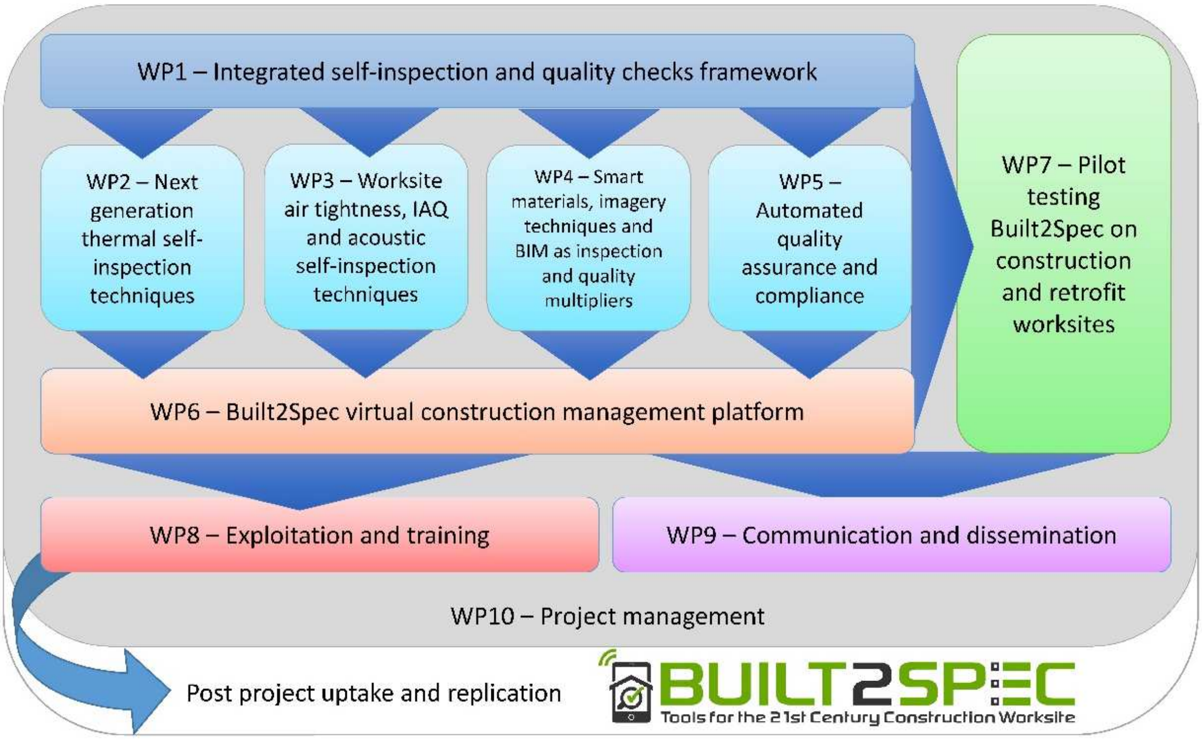

Fig. 2. Built2Spec approach.

3 SMART BUILDING COMPONENTS

3.1 Methodology

The Built2Spec project implements the novel use of embedded sensors in the precast concrete structural elements (as part of the WP4, see Figure 2). This is done in order to continuously monitor both, the structural and environmental performance of the building. Using strain gauges (e.g. [7], [8]) and thermistors (e.g. [7], [9]) cast into various building structural elements, such as slabs and walls, the building performance can be monitored not only at the construction stage, but through the entire lifecycle of the building.

The performance criteria for data measurement act as input requirements to the integrated Virtual Construction Management Platform (VCMP). Those measurements may include concrete temperature, moisture, strains, pH, chloride ion and early signs of reinforcement corrosion, all critical data for evaluating precast / in situ system performance (Figure 3).

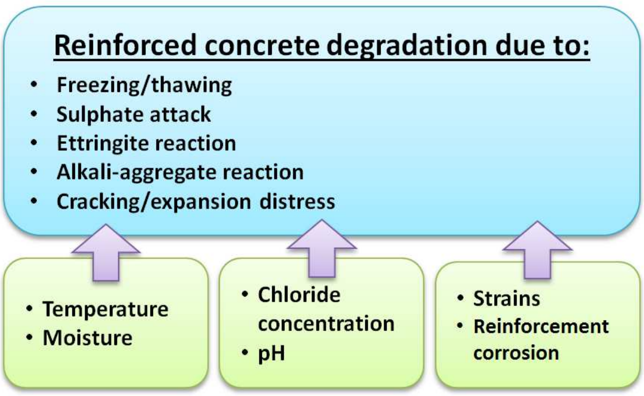

Fig. 3. Primary drivers for reinforced concrete degradation.

The BS EN ISO 9001:2008 Quality Management Systems standard [10] specifies systematic quality checking procedures that support the development of products that comply with customer and regulatory requirements. The Built2Spec project addresses the need for continuous self-inspection quality checks of building elements through their life cycle.

Thus, the environmental / structural monitoring of smart building components commences at the manufacturing stage of the precast elements, through the on-site installation and continues during the building commissioning and operation, and is underpinned by recognised quality management standards. The continuous monitoring and inspection of the data allows 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 (Figure 4).

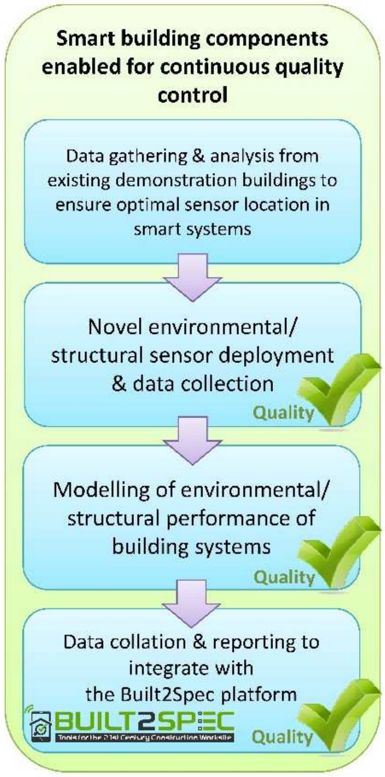

Fig. 4. Process of developing smart building components enabled for continuous quality control.

Following this, measured data is analysed and used to develop calibrated numerical models that predict building environmental and structural performance. This is done to ensure the design standards / guidelines for precast / in situ concrete systems are met under various conditions. The physical measurements collected during the project transfer directly into the overall Built2Spec VCMP in order to provide a user-friendly quality check tool for engineers, building managers, contractors and other stakeholders.

Thus, the state of the art relating to smart building components includes (Figure 5):

- Real-time physical measurement platform, including (i) site measurements, i.e. sensor-embedded construction elements and weather monitoring, and (ii) laboratory testing, i.e. concrete strength, coefficient of thermal expansion, etc.
- BIM database of performance of smart building components, i.e. a structured and consistent database of the environmental and structural performance of building systems through their life cycle phases, underpinned by standard quality checking procedures.
- Calibrated numerical models (finite element (FE), computational fluid dynamics (CFD)) of smart building systems that can predict building structural and environmental performance under various conditions (climatic / loading, etc.) allowing for further innovation in these components.
- The state of the art relating to smart building components will be underpinned by existing international quality management and environmental / structural performance standards and national building regulations (e.g. [11]–[17], etc.), and the state of the art research developed at NUI Galway (e.g. [18], [19]).

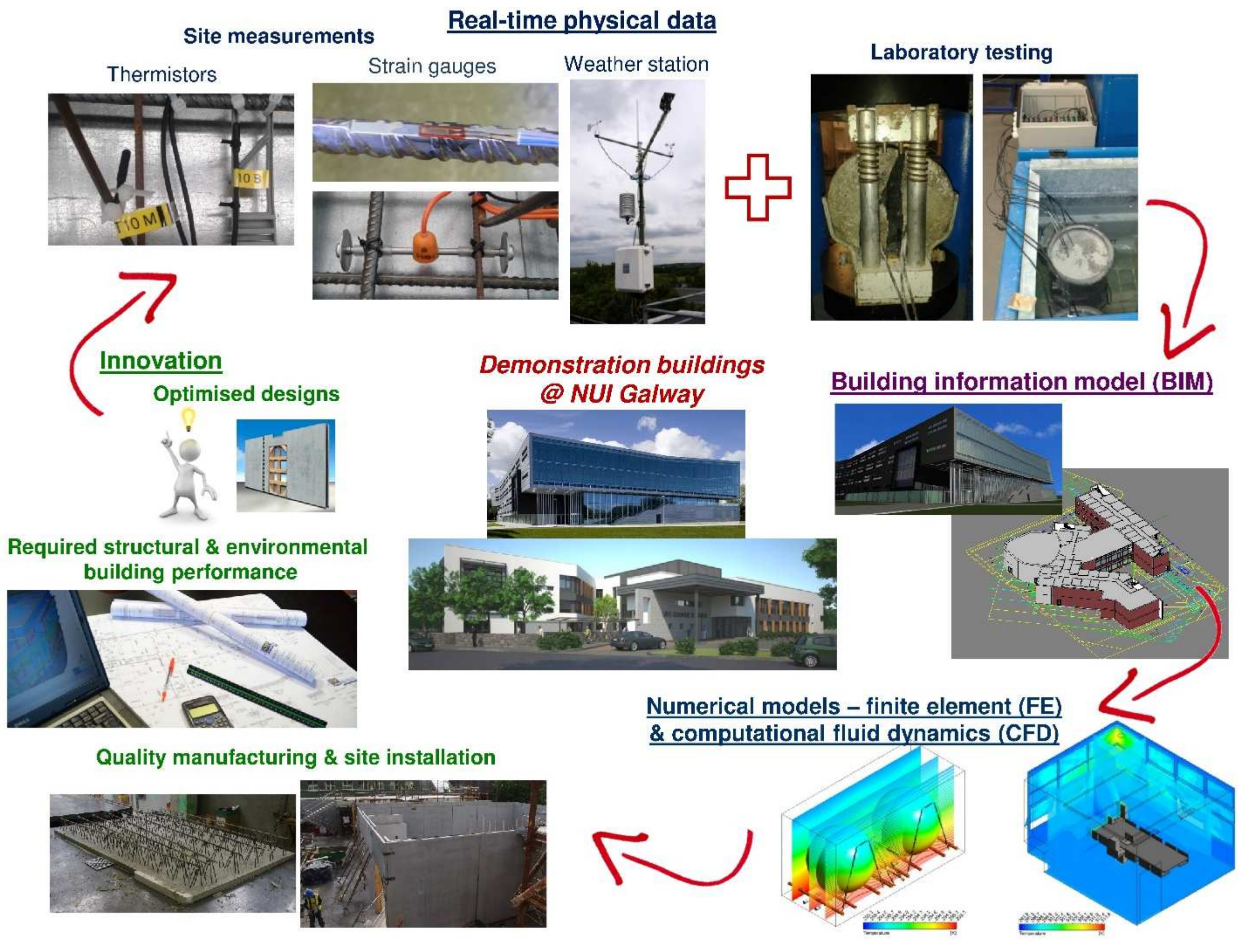

Fig. 5. Innovation of the smart building components.

3.2 Demonstrators

The measurements to support the development of the performance database for smart building components are provided by operating and under construction demonstration buildings, utilising existing concrete technology [20] and live weather monitoring at NUI Galway [21] (Figure 5). Demonstration buildings at NUI Galway include (Figure 6):

- **Engineering Building** [22], a 14 250 m^2 building (4 storeys) accommodating about 1100 students and 110 staff in the College of Engineering and Informatics. The building is equipped with the building management system (BMS) including weather monitoring. There are more than 260 strain and temperature sensors embedded in the building's precast concrete structural elements [20], over 140 sensors and meters measuring indoor air temperatures, humidity, noise and CO_2 concentration, water and energy consumption.
- **Institute for Lifecourse and Society** [23] is a 3 700 m^2 building (3 storeys) predominately built in a precast concrete technology [20]. It is equipped with about 120 temperature sensors embedded in the floor / roof lattice slabs and twinwalls, and about 60 stress gauges embedded in the floor lattice slabs.
- **Human Biology Building** [24] is an under construction 8 000 m^2 building (5 storeys) designed and constructed in the precast concrete technology [20]. There are number of strain and temperature gauges embedded in the precast and in situ concrete slabs [20].

Any additional measurements to establish material properties necessary for this work are carried out in the high-technology structural and environmental laboratories in the Engineering Building at NUI Galway [22]. The details of the measurement framework of the above mentioned demonstrators can be accessed at refs. [25]–[28].

a

b

c

Fig. 6. Demonstration Engineering Building (a), Institute for Lifecourse and Society (b) and Human Biology Building (image source STWA) (c) at NUI Galway.

4 CONCLUSION

This paper presents the overview, objectives and impact of the Built2Spec project, which brings together a new and breakthrough set of technological advances for self-inspection and quality assurance at the construction of energy efficient buildings. The project fills the gap in the availability of structured and systematic mechanisms to support the decision-making, execution and commissioning phases of construction processes. The Built2Spec will develop intelligent and automated ways to collect worksite data within a collaborative integrated framework, in order to minimise the gap between the intended and actual energy performance of new and retrofitted buildings.

Furthermore, this paper presents a methodology for the use of sensor-embedded construction elements, i.e. smart building components, for continuous performance self-inspection and quality checks in buildings. The innovative system for embedding sensors in building elements, collecting information from the sensors, utilising data from numerical models and presenting relevant information in a user-friendly, accessible manner will be extremely valuable to engineers, building managers, contractors and other stakeholders, and will support continuous self-inspection and quality checks to reduce the gap between the designed and actual building performance.

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