Strategies, methods and tools for managing nanorisks in construction

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Strategies, methods and tools for managing nanorisks in construction

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Abstract. This paper presents a general overview of the work carried out by European project SCAFFOLD (GA 280535) during its 30 months of life, with special emphasis on risk management component. The research conducted by SCAFFOLD is focused on the European construction sector and considers 5 types of nanomaterials (TiO_2, SiO_2, carbon nanofibres, cellulose nanofibers and nanoclays), 6 construction applications (Depollutant mortars, self-compacting concretes, coatings, self-cleaning coatings, fire resistant panels and insulation materials) and 26 exposure scenarios, including lab, pilot and industrial scales. The document focuses on the structure, content and operation modes of the Risk Management Toolkit developed by the project to facilitate the implementation of "nano-management" in construction companies. The tool deploys and integrated approach OHSAS 18001 – ISO 31000 and is currently being validated on 5 industrial case studies.

1. Introduction

The European construction industry (2013) contributes 8,8 % to the EU-28 GDP and employs 13,9 million people - 6,4 % of total employment and 29 % of industrial employment - in 2,9 million enterprises, most of which – 95 % - are SMEs with less than 20 operatives [7].

The use of manufactured nanomaterials (MNM) and nano-enabled products (NEP) in construction and the related infrastructure industries is an increasing reality, mostly in cement or concrete products, coatings or insulation materials and to a lesser extent in road-pavement products, flame retardant materials or textiles [1,12,13].

A majority of workers and their employers in the construction sector (~75%) are not aware that they actually work with MNMs and NEP. Detailed information about the product composition and their possible nano-specific health and safety issues is generally lacking and the information available for the raw material manufacturer is often lost while stepping down the user chain. As a consequence, it is very difficult for average construction companies to conduct a proper risk assessment and organize a safe workplace for its employees [27].

In this context, project SCAFFOLD is a three years industrial oriented idea (2012-2015), funded by EC under FP7, specifically addressed to provide practical, robust, easy-to-use and cost effective solutions for the European construction industry, regarding current uncertainties about the occupational exposure to nanomaterials. The aim of project is to develop, test, validate in real conditions and disseminate a new holistic, consistent and cost effective Risk Management Model (RMM), by integration of a set of innovative strategies, methods and tools developed by the project into consistent state-of-the-art OHS management systems (OHSAS 18001 and ISO 31000) (Figure 2).

The research conducted by SCAFFOLD is focused on construction and considers five types of nanomaterials (TiO_2, SiO_2, carbon nanofibres, cellulose nanofibers and nanoclays), six construction applications (Depollutant mortars, self-compacting concretes, coatings, self-cleaning coatings, fire resistant panels and insulation materials) and twenty-six exposure scenarios, including lab, pilot and industrial scales (Figure 1).

2. Overview of project results in the areas of risk prevention, risk assessment and risk protection

Within SCAFFOLD project, different safe-by-design strategies has been designed in order to increase the safety of nanomaterials and nano-enable products for construction. Concretely, the first strategy involves the preparation of highly concentrated dispersions (TiO_2, SiO_2) instead of using powders directly for safer transport and handling. Thus, apart from achieving excellent results regarding particle size and stability with the mentioned new dispersions, the effect and performance of the nanomaterials was perfectly maintained. Additionally, specific safe-by-design strategy was used in order to modify some nanoclays so that their incorporation in fire resistant panels results in lower toxic emissions.

In addition, we studied the effects of mixing conditions and clay loading level on mechanical properties and fire performance of glass fibre composites. Clays with different organomodifier content and type were also investigated. For the materials studies, there were no differences in fire performance and mechanical properties with different mixing conditions. The positive conclusion from this is that workers could use lower energy processes to incorporate clays into polymer resins, helping to limit the amount of dust produced. With regard to the different clays produced, there was found to be very little difference between in the fire performance of the resulting composites. Anecdotally, one of the novel clay samples was observed to be less dusty than the others, which could have potential "safe-by-design" implications; however further qualitative analysis is required in order to confirm this finding.

Specimens containing either TiO_2 or TiO_2-on-sepiolite in bulk and sol-gel coatings have been prepared and tested – a slight increase in mechanical properties was observed in bulk additions, but there was no significant difference between the TiO_2 and TiO_2-on-sepiolite. TiO_2-sepiolite is a safer additive than TiO_2 free nanoparticles due to the fact that this special clay is used to improve the dispersion of TiO_2 nanoparticles and to attach the nanoparticles on the surface. Samples of self-compacting concrete with nano-SiO_2 (1 and 5 %wt.) have been prepared and tested. In this case it exist also a slight increase in mechanical properties. Nano-SiO_2 has been supplied in a dispersion that is safer than same material in powder.

SCAFFOLD project measured particle release and occupational exposure (inhalation, dermal) at pilot scale, lab scale and in real scenarios, considering: five NOAAs (TiO_2, SiO_2, CNF, CeNF and nanoclays), six applications (depollutant mortars, self-cleaning coatings, self-compacting concretes, fire-retardant panels, coating laminates and insulations) and five main scenarios (Manufacture of NMs, manufacture of products containing MNMs and application, machining (drilling, sawing), demolition and accidental fires). It is important to highlight that in the construction sector the exposure to mixed types of dust is extremely common and results in much higher levels than the exposure to MNMs, which are generally included in a very low concentration in the products (typically not exceeding 1,5 %). In addition, attention is more focused on traditional contaminants as e.g crystalline silica (carcinogenic to humans, IARC).

The highest release of particles was measured during machining (drilling and sawing) of samples of hard materials like concrete and laminate coating, with no clear difference between conventional and nano-enabled materials, and with no observation of free nano-objects (SEM analysis). Occupational exposure measured (particle concentration of NOAA) was below proposed NRV limits. The highest mass concentration has been measured during the cleaning task in the manufacturing process of nano-TiO_2. Mass concentration of the specific nano-object at the personal breathing zone has been measured for the scenarios related to nano-TiO_2 and CNF and was below proposed OELs by NIOSH and SCAFFOLD. New measurement campaigns are scheduled during the development of industrial case studies (Figure 3).

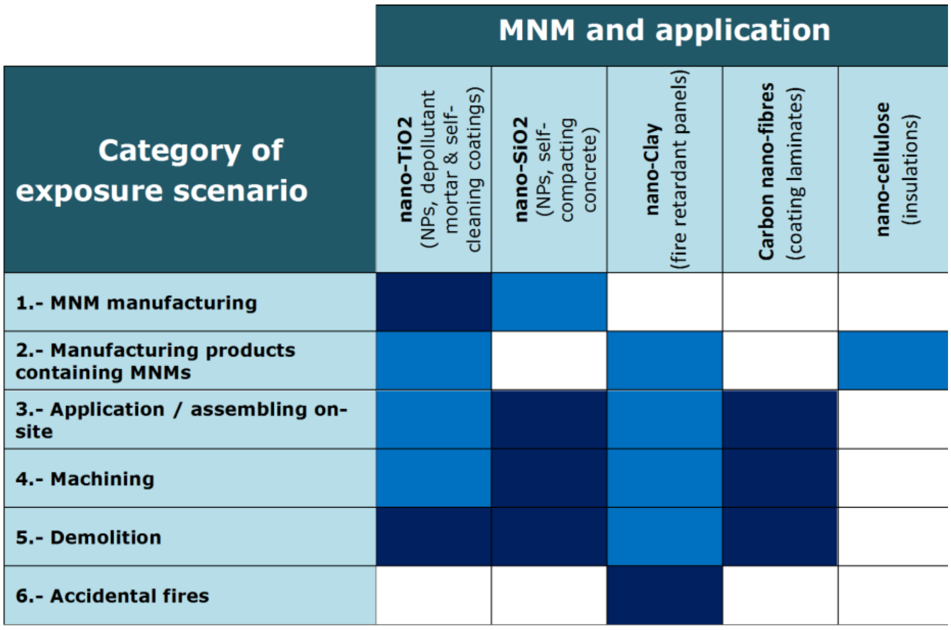

Figure 1 Exposure scenarios selected by project SCAFFOLD (Dark blue, lab and pilot scales; light blue, industrial scenarios).

Reaction to fire tests performed with conventional and nano-enabled materials showed differences on fire behaviour linked to the presence of the nano-objects. However, none of the nano-objects introduced in the materials were identified in the effluents from the combustion, with the possible exception of nano-clays from the fire retardant panels.

Based on the available data on the toxicological properties of the nanomaterials, recommendations for occupational exposure limit values have been proposed for TiO_2, SiO_2, Carbon Nanofibers (CNF), Cellulose Nanofibers (CeNF) and Nanoclays.

Concerning the collective protection, investigations were carried out during experimental campaigns, in nine rooms with different ventilation systems. It was confirmed that only in the room with positive pressure ventilation and when works were conducted in the glove box, particles from the processes were not transferring to the room air.

The efficiency of different types of current respiratory protective devices intended for use in construction as well as three types of clothes generally used by workers on construction sites, were tested with different nanoaerosols in order to classify them and enable a proper selection for different workplaces and hazards. The Total Inward Leakage (TIL) of nanoparticles was realized with a breathing manikin simulating natural human movements and speech. The highest TIL levels were found for speech simulation and simulation of up and down head movement. The highest effectiveness of protection was recorded for the full-face mask used with P3 filters and the TH2 powered filtering device incorporating a hood.

The observation of PPEs involved in real scenarios at industrial partners' workplace showed that the actual gloves, masks and Tyvek clothes are efficient towards nanoparticles incorporated at realistic concentrations (between 0,4 and 1,7%) in a material. All the mortars studied contained just few percentage of nanoparticles, just enough to bring beneficial effects to the material. Whether in powder form (synthesis of nanoparticles, manufacturing of the mortar) or in solid state (mortar with water, applying on a wall) or in sol-gel state (liquid mortar), we never observed SiO_2, TiO_2, nanoclay or nanocellulose inside PPEs. Regarding the nature of the clothes, the rain coating was the most efficient material, with no diffusion observed at all (aerosol and liquid). The polyester 65%/cotton 35% material was efficient only for SiO_2 aerosol and the fleece jacket for SiO_2 aerosol and TiO_2 aerosol.

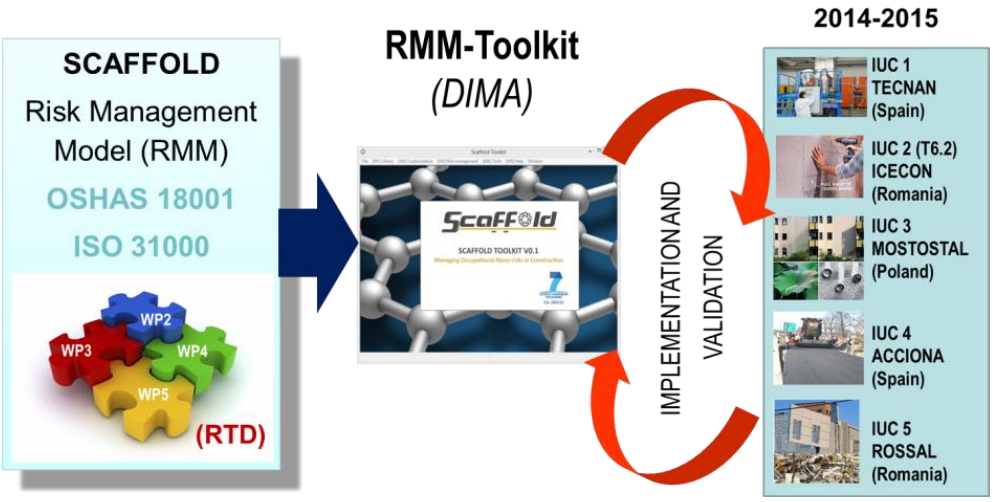

Figure 2. Integration of the results of research in the SCAFFOLD-Toolkit and validation.

3. SCAFFOLD approach for managing nano-risks in construction

3.1. Background

The most common approach and usually the first choice to tackle the uncertainly related to risk assessment and management of MNM is Control Banding (CB) [2,5,6,10,14,25]. This approach is particularly useful in work situations in which information on hazards, exposure levels and risks are limited. It is also valuable for SMEs for its simplicity.

There are some CB tools already available [2], but they have not been developed for the construction sector, which is a rather different kind of work environment compared to e.g. the chemical industry. EU-OSHA [6] developed a specific document introducing a number of such control banding risk management tools, to aid in the selection of appropriate workplace prevention measures. An international standard has been also recently produced by ISO (ISO 12901-2: 2014) [10].

From the viewpoint of management systems, OSHAS 18001 [3,4] is the internationally recognized and adopted standard for Occupational Health and Safety, designed to help organizations to implement a framework that identifies and controls health and safety risks, reduce potential accidents, aids legislative compliance and improves overall performance.

OSHAS 18001 implements an approach based in the PDCA model, fully compatible and easy integrable with other management standards like ISO 9001 and ISO 14001. One of the key aspects of the management system is the continuous improvement, which allows companies to improve their performance in a continuous way, taking into account the technical and economical limitations, but also the possibilities brought by the new technology, new knowledge and new risks. This is a key issue, as nanotechnology knowledge is subject to continuous changes due to technical and scientific advances, and because of that is it necessary to provide companies with a tool capable not only to manage current risks buts also to identify and manage the new ones (coming, for instance, from new nanomaterials or just from the improvements made in detection capabilities).

Near 55.000 companies have been already certified according with OHSAS 18001, and the increase in the number of certificates is exceptional: between 2007 and 2009 the increase was as high as 73%. OSHAS has had a great impact in SMEs and some studies show that more than 80% of certified companies are SMEs, and that particularly the 50 to 250 workers interval represents more than 50% of companies. Regarding construction, this sector is leading the implementation of OHSAS (37%), showing the commitment of the construction companies, especially SMEs, to the improvement of occupational health in Europe. In fact, according with the above-mentioned study, 97% of the companies certified according to OSHAS 18001 where already certified according to ISO 9001 and 91% according to 14001. These figures show the importance of the compatibility in the integration of the environmental, quality and labour safety issues in the organizations [16].

However, the capability of OSHAS 18001 to deal with new risks, and particularly those related to nanomaterials manufacturing, use and disposal has yet to be tested. In this respect, the European project SCAFFOLD will answer those two questions: the capability of OHSAS 18001 to deal with "nano-risks" and eventually its gift for being implemented by SMEs.

ISO 31000 is the international standard for risk management. It provides principles, framework and a process for managing risk [9]. However, ISO 31000 cannot be used for certification purposes, but does provide guidance for internal or external audit programmes. This international standard also helps to boost health and safety performance, establish a strong foundation for decision making and encourage proactive management in all areas. Organizations using it can compare their risk management practices with an internationally recognized benchmark, providing sound principles for effective management and corporate governance.

With over 127 countries currently using OHSMS standards [15], there's a worldwide need to harmonize health and safety management systems using an international standard and share best practices. Inspired by the well-known OHSAS 18001, ISO is currently developing ISO 45001 [11]. There are 50 countries and international organizations, including the International Labour Organization, involved in this work. The future standard will also be aligned with ISO 9001 and ISO 14001. The new standard is expected to be published in late 2016.

3.2. Control banding approach

The Finish Institute of Occupational Health tested the applicability/usefulness of the CB approach [18], more specifically the freely available control banding tool *Stoffenmanager Nano 1.0* [5,25], in assessing and managing risks of nanomaterials in the construction sector. The results indicate that the tool is applicable in some of the studied industrial workplaces. In other cases, the evidence that the raw material contained engineered nanomaterials was not available. Thus, the hazard assessment was the most difficult part, because it was difficult to identify the nanomaterial from the products.

Furthermore the ISO 12901-2 approach has been implemented in the Toolkit [20] and one of the partners of the project consortium is currently finishing a customized tool for the sector.

3.3. The Risk Management Model (RMM)

Although there are some private schemas dealing with nanomaterials H&S management, particularly the CENARIOS model [26], SCAFFOLD will avoid creating new systems, which are annoying to implement and probably not the result of the consensus process, and will try to show the opportunity of using OSHAS 18001, with the necessary specific elements and recommendations, specially for its implementation in SMEs, in the identification and management of nano-related risks. Moreover, SCAFFOLD project will follow a new approach to incorporate the principles for risk management contained in the recent global standard reference ISO 31000 [9].

The RMM presents itself and innovative conceptual work taking into account derived from ISO 31000 requirements and OSHAS 18001 [17]. It is based on a conformity assessment extended scheme and the PDCA cycle like OSHAS 18001. The outline is very similar to the most implemented management systems ISO 9001 and ISO 14001. This design for the model allows the integration with the other management systems especially for the common requirements (systems requirements as document control, audits, training, etc). The model has been designed using requirements of OHSAS 18001 (structure, elements, etc.) with additional requirements derived from the guidelines established in ISO 31000.

The RMM includes specific considerations on initial review, monitoring and audit and can be certificated. The implementation of this RMM will allow the organization to consider MNMs risk into OHSAS system [19]. On the other hand, if the organization has no experience on a systematic approach for managing its occupational health and safety risks, the MNMs RMM implementation could be the first step for a more complete and organized perspective of OH&S risks. One organization that proves the successful implementation of this model should ensure all interested parties that has an appropriate MNMs risk management.

The main difficulties encountered in the model design were related with · the fact that ISO 31000 is not a requirement standard but a guideline, then does not include specific rules it is made on recommendations; the conversion of recommendations from ISO 31000 into specific requirements; · the analysis of this requirements that should be added to complete OSHAS 18001; · the decisions on the risk assessment approach in the model taking into account that both references have different definitions; ·the design to be applied to all type, size and context organization with particular emphasis in SMEs.

The level of detail and complexity of the RMM, the extent of documentation and the resources devoted to it depend on a number of factors, such as the scope, the nature of its activities, the organizational culture and also the size of an organization. This is the case in particular for SMEs that could need a specific and adapted Toolkit for RMM implementation. In this respect, a specific guide to establish criteria for interpreting the RMM and facilitate implementation in the SME construction companies in to the entire life cycle of the construction sector, has been drafted and implemented in the Toolkit (Customized approach for SMEs) [22,23] .

3.4. The Toolkit

The RMM-Toolkit represents the integration of all the solutions developed for risk management during the project in a software tool, friendly, easy to use and customizable for SMEs. It consists in a standalone desktop application for the Windows platform [20, 21, 22]. The Toolkit is structured into: 1) Five operational modules (Library, Customization, Risk management, Tools and Help) (Table 1), 2) two setups, a general setup for large or advanced companies in risk management, and a customized setup for SMEs and 3) Two operational modes (Table 2), learning and risk management. In tables 1 and 2 the main characteristics and content of the modules and operating modes are displayed.

The main tools for risk management in the Toolkit are [20,21]:

1) <u>Risk management</u>: opens the checklist for diagnostic, implementation or audit. The checklist enables the user to enter comments and generate bar charts. The Toolkit will include two check list depending on the set up decided by the company, the general check list (275 questions) is for general set up and the reduced check list (150 questions) is principally for SMEs set up.
2) <u>Risk assessment</u>: opens the risk evaluation tool. This window displays a list of processes, tasks and scenarios. Each scenario can be characterized with both quantitative and qualitative methods. The quantitative method allows the user to enter the exposition and reference values.

The tool will then calculate the exposure value and, according to the configured thresholds, the risk level. The qualitative method implements the control banding approach ISO 12901-2. The user can navigate through these charts to get a hazard band (A – E) and an exposure band (1 – 4). This characterization leads to another risk level. For each scenario, a set of control measures can be selected, allowing the user to specify whether they are already implemented or not.

3) Planning: opens a tool to schedule the implementation of the control measures specified in the risk evaluation tool. For each control measure, the user can select the expected implementation date, the actual implementation date, the progress, the responsible and the associated cost. This planning can be exported to Excel.
4) KPIs: allows the definition, customization, calculation and visualization of Key Performance Indicators.
5) Documents and templates: gives access to a list of Word templates with procedures, instructions, registers and OHS manuals.

Table 1. SCAFFOLD Toolkit: Software modules [20, 21, 22]

Module	Description
1. Library	It provides a library with documentation to help the companies of the construction sector to deal with the risks arising from MNM.
2. Customization	It allows companies to customize the application to their processes, tasks, scenarios and size. It uses the Module 1 to facilitate data input and generate the company profile.
3. Risk Management	It enables the initial assessment, implementation and audit of RMM guided by a step-by-step dialog. This module deploys two different setups, depending on the company profile (Large company or SME).
4. Tools	It contains the toolbox for nanosafety management.
5. Help	It gives access to miscellaneous options: file management, configuration, and help (User manuals).

Table 2. SCAFFOLD Toolkit: Operation modes [20, 21]

Operation mode	Description
Learning	The toolkit is used for training (e.g. toolbox), general information and communication (e.g. NOAA, hazards, control measures, good practices, etc). Only modules 1 and 4 are operating.
Risk Management	Customized mode. The toolkit is used for diagnosis, implementation, monitoring, auditing and improving the management of nanorisks in a specific construction company. All modules are operating.

3.5. The library of solutions for risk management

Project SCAFFOLD will produce by April 2015 a Library of Solutions to facilitate the diagnosis, implementation and audit of nano-risks management in construction companies (large companies and SMEs). The library will include: 1) a handbook for managing nanoriks in construction, 2) four quick guides (risk prevention, risk assessment, risk protection and risk management) and 3) the Toolkit (software).

Recently the CEN/TC 352 "Nanotechnologies" decided to accept a New Work Item (NWI) Proposal relating to CEN/TS "Manufactured nanomaterials (MNMs) in the construction industry. Guidelines for occupational risk management”, promoted by project SCAFFOLD.

3.6. Testing and validation stage
The SCAFFOLD approach is currently under validation in five Industrial Use Cases (IUC). The IUC have been selected to cover different applications, size of companies, exposure scenarios, countries with different safety cultures and different OHS needs (Table 3).

Since the IUCs show different characteristics and needs, every IUC deploys its own customized plan [24]. All these activities will be developed by using the RMM-Toolkit. In all cases, the plan consists of five basic steps: 1) Information and training first; 2) Diagnosis of the OHSMS, 3) Implementation, monitoring and internal audit, 4) External audit and finally 5) Reporting of the company and auditor (Figure 3).

Table 3. The five Industrial Use Cases (IUC) of project SCAFFOLD [24]

IUC	Company	Country	Size	Exposure scenario	MNM
1	TECNAN	Spain	SME	Manufacturing nanomaterials : nano SiO_2, powder	SiO_2
2	ICECON	Romania	Large	Manufacturing nano-enabled products: Fire resistant panels	Nanoclay
3	MOSTOSTAL	Poland	Large	Use of nano-enable products in building construction: Application of coatings with three methods: brush, roller or spray gun)	TiO_2
4	ACCIONA	Spain	Large	Use of products containing nanomaterials in civil construction: Construction of a concrete slab	TiO_2
5	ROSSAL	Romania	SME	End of life of nano-enabled products: Demolition of fire resistant panels	Nanoclay

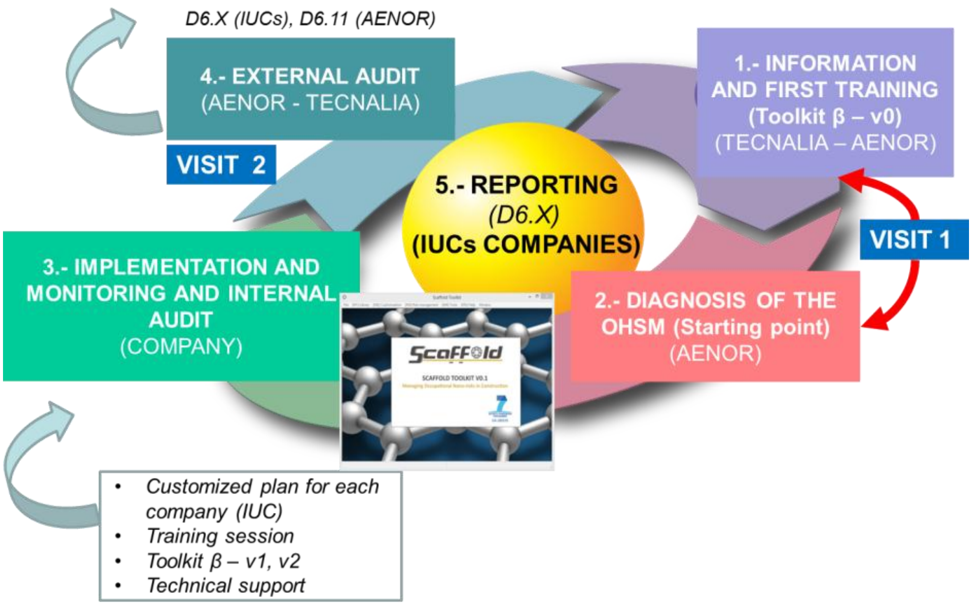

Figure 3. Stages for the deployment of the Industrial Use Cases (IUC) in construction companies, during the demonstration stage of project SCAFFOLD [24]

4. Conclusions
Nanotechnology is making its advance faster than the safety management related to it. Development of new methods, strategies and tools for risk management based on solid scientific knowledge may take a long time. But the European construction industry is already manufacturing and handling nanomaterials and nano-enabled products and workers are exposed to nano-risks.

Consequently, until having the total knowledge available, efforts should be made to provide the construction industry with intermediate management solutions, based on the state of the art, to make decisions with minimal uncertainties. It means the need to translate and encapsulate the results of current research in a battery of practical methods, strategies and tools for the management of nano-risks, directly usable by industry and companies that provide services to industry. All these tools should be updated with the evolution of the state of the art.

The project SCAFFOLD follows this approach and is ready to provide the construction industry with a package of practical solutions, to enable the management of nanorisks in large companies and SMEs.

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