Marie Skłodowska-Curie Actions

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 642453

Training in Reducing Uncertainty in Structural Safety

D3.11 Final Report

WP3 - Structured Training

Revision [final version]

Deliverable Number	Deliverable Title	Lead Beneficiary	Type	Dissemination Level	Due date
D3.11	Final Report	NUID UCD	Report	Public	31-Dec-2018

Start Date of the Project: 01-Jan-2015 Duration: 48 months

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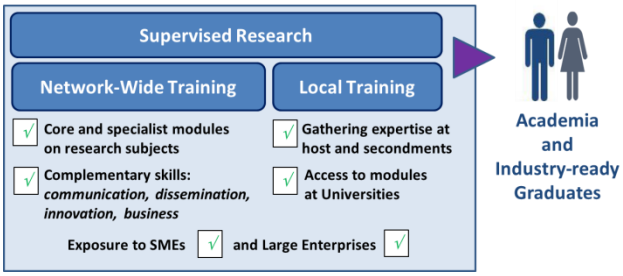
Executive Summary

This report explains the training carried out in work package WP3 - Structured Training - within the TRUSS ITN project. The training programme structured in two ways:

- Network-wide and Local training activities.
- Supervised research towards a doctoral award.



Structured training.

TRUSS holds network-wide meetings approximately every 6 months. During these meetings, Early Stage Researchers (ESRs) had an opportunity to practice their communication skills, and to receive academic and/or industrial training and supervision. ESRs joined TRUSS ITN between September and December 2015. Three training weeks delivering intensive and highly focused modules took place in UNOTT, UK (30 Nov - 4 December 2015), in UPC, Spain (16 to 20 January 2017), and in TCD and UCD in Dublin, Ireland (15 to 19 January 2018). Three additional annual plenary meetings containing training elements such as keynote lectures, technical presentations and technical visits were held in Santander, Spain (16 - 17 June 2016), Lloyd's Register, London, UK (24 - 25 May 2017) and Dublin, Ireland (29 - 30 Aug 2018). It is also worth to mention the midterm review meeting, held in Arup, Ireland (1-2 December 2016), where both supervisors and ESRs received feedback and training suggestions from the Project Officer (PO) and External Expert.

The 1st training week in UNOTT consisted of core modules (such as: safety quantification, reliability analysis and life cycle assessment), specialist modules (updating of random variables, material and load modelling, fault diagnostics methods and structural health monitoring), and soft skills (communication, presentations and research plan). A team activity was also conducted where groups had to design a sensor layout and itinerary for a chosen Bridge, considering real-life challenges i.e. time constrictions, limited budget, etc.

The 2nd training week in UPC included core modules (vulnerability and risk assessment; uncertainty quantification and propagation for sensitivity or reliability purpose; practical reliability engineering – case studies; survival analysis and discrete event simulations applied to structural reliability; advanced finite element modelling), specialist modules (multi-level Monte Carlo methods for stochastic analysis and robust optimum design; reducing uncertainty in structural safety through static non-destructive tests; workshop on observability; techniques for uncertainty reduction; reducing uncertainty through the structured expert elicitation: justification and methodology), and soft skills (knowledge management: the path to innovation; responsible conduct in research and innovation).

The 3rd training week was an educational collaboration between TCD and UCD aimed to have a positive impact on individual's personal and professional development of each ESR by nurturing entrepreneurial thinking. ESRs were trained in developing and nurturing creativity, innovation, entrepreneurship and teamwork. Within business and entrepreneurship skills, the following aspects were covered: entrepreneurship, intellectual property, management, ethics and exploitation.

Following a request from the ESRs, a 4th training week was organised with focus placed upon project management. The latter took place in UCD, Dublin (11 - 14 June 2018). This 4-day Project Management course was hosted by UCD, and it provided ESRs with a minor award that sits at Level 6 on the National Framework of Qualifications. The latter allowed ESRs to take the Certified Associate in Project Management (CAPM) exam and to obtain the Project Management Institute (PMI) certificate. Chapter 1 reviews contents provided in the four training weeks.

All ESRs were registered on a PhD programme in one of the four academic beneficiaries. The primary support to help ESRs in conducting the high-level research necessary to achieve a PhD was their main supervisor and Doctoral Studies Panel (DSP) composed by consortium experts. In addition to the formal supervision structure, each ESR was required to maintain a Personal Career Development Plan (PCDP). Following presentations by the ESRs at the network-wide meetings, the consortium provided feedback and each ESR met with his/her DSP in a focus group that discussed the PCDP and future plans of action. Each ESR submitted a total of 6 PCDPs in January and July 2016, January and June 2017, and January and June 2018. This structure played a major part in informing the direction of the research of the ESRs and their training and empowered the fellows to take ownership of their projects. Chapter 2 gives details about DSP meetings and supervision arrangements.

In addition to taught modules, another very significant form of training was on-the-job training, which ESRs experienced in the local research group at their host, and also at the institution/s where they were seconded. The TRUSS network, composed by 6 Universities, 11 Industry participants and 1 research institute from 5 European countries, offered a rich variety of secondment opportunities. Chapter 3 describes and justifies the secondments of each ESR.

The network-wide training programme was extended by a range of local training activities consisting of advanced research methods, project management, language courses, transferable skills and communication modules made available to the ESRs. As a result, ESRs attended more than 1400 hours of scientific/technical theoretical courses or seminars, and >1600 hours in practical laboratory/field tests related to their research, i.e., averaging over 300 hours of local scientific/technical training per ESR. They also invested > 700

hours in language courses, > 250 hours in other taught courses on soft skills, and > 150 hours in teaching activities - supervising, demonstrating or providing tutorials-, which leads to approximately 75 hours of local complementary training per ESR. Additionally, ESRs participated on average in 10 conferences, workshops or meetings with professional associations where they had the chance to practise their communication skills and also to interact with other experts and learn from their experience. Last but not least, ESRs also participated in outreach activities where they tested their communications skills via face-to-face interaction with the general public. Chapter 4 summarizes the local training undertaken by all ESRs.

Chapter 1: Network-wide training weeks

This chapter describes the four main network-wide training events that took place within TRUSS. The 1st and 2nd training weeks were mostly composed of scientific/training contents, with a smaller proportion of complementary/soft skills. They were held by UNOTT, UK (approximately 3 months after arrival of the ESRs), and by UPC, Spain (1 year after the 1st training week). The 3rd training week placed focus upon business and entrepreneurship skills, and took place in both TCD and UCD, Ireland (1 year after the 2nd training week). The 4th training week dealt with project management, was hosted by UCD and took place 6 months after the 3rd training week.

1.1 TRAINING WEEK 1

First training week in TRUSS ITN was held in University of Nottingham (UK) from Monday 30th November to Friday 4th December 2015.

Modules for the training week were classified into core research modules, specialist research modules, team activities and research seminars. The distribution and module titles in this training week are given in Table 1. This report gives a detailed description of the contents for each of these modules. Lecture notes for all modules were made available to Early Stage Researchers (ESRs) via google drive.

Table 1. Modules and distribution of training week 1

Type of Module	Name of Module	Hrs.
Introduction	Introduction to TRUSS	1
Core Research Modules	Methods of safety quantification	1
	Reliability analysis	1
	Life cycle assessment	1
Specialist Research Modules	Updating of random variables using on-site information	1
	Material modelling	1
	Load modelling	1
	Overview of fault diagnostic methods – part one	1
	Overview of fault diagnostic methods – part two	1
	Structural health monitoring	1
Communication/transferable Skills Modules	Planning your research	1
	Presentation skills	1
Team Activities	Innovation workshop: Case Study	10
	Team building activity	7
Research Seminars	Presentations by Early Stage Researchers on their research	2

The following twelve ESRs attended the training week:

- ESR1. Sofia Antonopoulou (UCD)
- ESR3. Alberto González Merino (ENSA)
- ESR4. Rui Teixeira (TCD)
- ESR6. Giulia Milana (Lloyd's Register EMEA)
- ESR7. Farhad Huseynov (FSDL)
- ESR8. Barbara Heitner (Phimeca)
- ESR9. Matteo Vagnoli (UNOTT)
- ESR10. JJ Moughty (UPC)
- ESR11. António Barrias (UPC)
- ESR12. Daniel Martínez Otero (UCD)
- ESR13. Federico Perrotta (UNOTT)
- ESR14. Siyuan Chen (UCD)

ESR2 Shah Nur Alam Sourav and ESR5 Guang Zou were unable to take part in the training week due to VISA issues.

At the end of the training week, answers to a confidential questionnaire were gathered from ESRs to identify those modules found more useful for the project and for their future career and to propose new modules to cover their needs or a follow-up to existing ones in a future training event.

1.1.1 Introduction to TRUSS

Speaker: Loreto Manriquez, Project Manager.
Objective: To give ESRs an overview of the project with emphasis on the compliance with the Grant Agreement.
Description: Fellows were given a welcome and had the opportunity to introduce each other. The module included a brief introduction to Horizon 2020 and Marie Sklodowska-Curie ITNs, TRUSS ITN objectives, structure, budget, timeline, means of communication and ESR's rights and obligations. All TRUSS ITN Work Packages were described. The need to provide inputs for "WP2 - dissemination and outreach" was highlighted (i.e., publications, social media, website, blogs, etc.).

Module on introduction to TRUSS

CORE RESEARCH MODULES

Core research modules provide an overall picture of the structural safety problem, the general theme that encompasses all projects in TRUSS.

1.1.2 Methods of safety quantification

Speaker: Dr Luis Neves, University of Nottingham
Objective: To gather an understanding on the methods to measure/assess safety of a structure, the perfect equilibrium between safety and cost, the methods to compute structural risk, the definition of an acceptable level of risk, the sources of uncertainty in a risk analysis, and how to model uncertainty associated to random variables.
Description: When employing a global safety factor, a single coefficient is employed. However, a similar coefficient of safety can result in very different safety levels. When using partial safety factors, a safety coefficient is applied to each

variable (each load is multiplied by a different safety factor, and each material and model is divided by a different safety factor). The values of these coefficients depend on the uncertainty associated to each variable. Compared to a global safety factor, partial safety factors lead to a more uniform level of safety across different structures, less unsafe structures and less over designed structures. A third alternative is the use of reliability analysis, which requires more information and it is computationally more expensive but it overcomes most limitations of partial safety factors.

Risk can be defined by the sum of the probability of occurrence of a failure by the consequences/cost. It must be as low as reasonably practicable. The overall costs (risk + mitigation measures) must be minimized. Codes are calibrated to achieve a uniform level of safety depending on the level of consequences of failure.

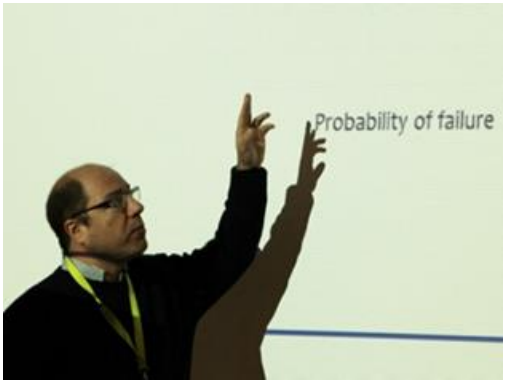
Sources of uncertainty exist in loading, weather conditions, material properties, deterioration, models, costs, etc. They can be classified into aleatory uncertainty, model uncertainty, statistical uncertainty, inherit uncertainty, model and statistical uncertainty. Available data can be subjected to a statistical analysis and used to build a probabilistic model that will be the basis for calculating probability of failure and to carry out a risk analysis that will assist in taking a decision regarding a structure. There is a consistent method to model uncertainty using cumulative density functions and probability density functions. Relevant distributions include normal, log-normal, exponential, gamma, beta and extreme distributions (Gumbel, Frechet, Weibull). Recommendation on best suited distributions for specific loads and material strengths are provided.

Module on methods of safety quantification

1.1.3 Reliability analysis

Speaker: Dr Luis Neves, University of Nottingham
Objective: To bring awareness of advantages and disadvantages of reliability analysis compared to partial safety factors, and to review the available methods of reliability analysis.
Description: The cost of repairing or replacing some structures is so high that a reliability analysis is justified for a more accurate assessment of structural safety. The method of reliability analysis can be analytical (low computational cost but requires gradient of limit state function), simulation (simple but computationally expensive) or a combination of both. In the simulation method, probability of failure is computed by generating samples of all random variables, and then counting how many lead to failure. The number of samples can be reduced employing an importance sampling technique. The true limit state function can also be replaced by a simpler function. Then First-Order Reliability Method (FORM) or Monte-Carlo are used to evaluate the probability of failure.

Levels of safety assessment are reviewed and examples are provided. They go from Level I (uncertain parameters are modelled by one characteristic value, i.e., Eurocode) to Level IV where the risk is used as a measure of the reliability. In Level II, uncertain parameters are modelled by mean values, standard deviations and correlation coefficients. In Level III, uncertain quantities are modelled by their joint distribution functions.
For existing structures, the cost of increasing safety is very high, and the uncertainty in most parameters and the remaining lifetime is smaller than in a new structure. Since the risk increases with exposure, risks are compared in a common timeframe. Meaning the annual probability of failure should be the same, and short life means smaller lifecycle probabilities of failure.



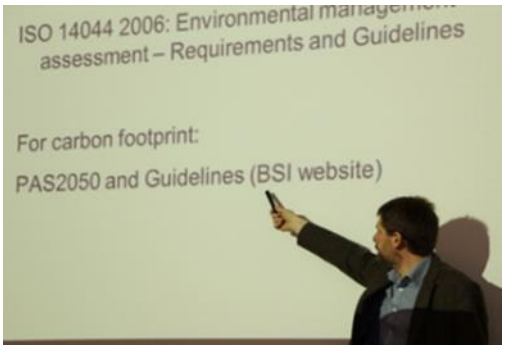
Module on reliability analysis

1.1.4 Life cycle assessment

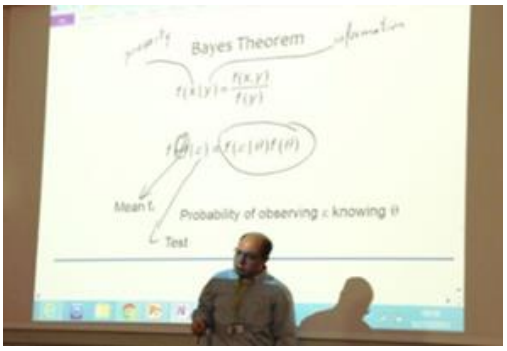
Speaker: Dr Tony Parry, University of Nottingham
Objective: To understand what a life cycle assessment is and the methodology needed to carry out this assessment.
Description: Life Cycle Assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product over the entire period of its life cycle, by: (a) compiling an inventory of relevant inputs and outputs of a product system; (b) evaluating the potential environmental impacts associated with those inputs and outputs; and (c) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

Standards ISO 14040 2006 and ISO 14044 2006 for life cycle assessment and PAS2050 for carbon footprint are reviewed with focus on the steps of the life cycle assessment framework including:

- Goals and scope definition
- Inventory analysis
- Impact assessment
- Interpretation: Identification of significant issues; evaluation by completeness check, sensitivity check, consistency check, other checks; conclusions, limitations and recommendations.
- Direct applications: Product development and improvement; strategic planning; public policy making; marketing; other.



Module on life cycle assessment



Module on updating of random variables using on-site information

SPECIALIST RESEARCH MODULES

Specialist research modules focus on specific aspects of quantification of uncertainty in structural safety. Contents include how to model random variables and those specific to materials and loads. Also, how to identify damage from measurements in an existing structure or how to monitor structural health and performance on a continuous basis.

1.1.5 Updating of random variables using on-site information

Speaker: Dr Luis Neves, University of Nottingham
Objective: To identify the differences between new and existing structures regarding safety, to be able to judge if a structure with a specific degree of deterioration can remain opened for use or needs to be closed, to be able to use Bayesian updating to define variables and a reliability index more accurately.
Description: When analysing an existing structure, information unavailable in the design phase can be obtained via non-destructive testing, proof loading tests and inspections. According to the level of assessment, there are strength and load models, calculation models and assessment methodologies that vary in complexity. The presence of damage means that the strength of the structure is lower than initially estimated, and as a result, it does not comply with the code anymore. Numerical examples of the cost of providing additional strength in the design phase or to an existing structure are used to illustrate the points above.

A practical case where it is needed to decide if a bridge can remained opened (or not) to traffic for one year more, is presented. When applying a code based assessment, the bending moment strength shows to be insufficient. Using FORM analysis, the reliability index is below the acceptable threshold, and consequently, the bridge should be closed. Bayesian updating is then used to carry out a more accurate assessment of structural safety. In the process, new distributions of concrete strength are updated based on tests. Although in some simple cases, expressions for the final (posterior distribution) can be derived, some sort of simulation must typically be used. Finally, the Bayesian updating algorithm leads to a reliability index higher than the acceptable threshold, i.e., the structure is found to be safe.

1.1.6 Material modelling

Speaker: Dr Ciaran McNally, University College Dublin
Objective: To understand the characteristics of the material we are interested in, how it relates to performance, and how we can measure and model material parameters/performance. To know how to allow for deterioration mechanisms into the material performance.
Description: The tail of the resistance curve is very important when establishing if the structure is safe. The latter is a function of materials, geometry and time. The following materials and key properties are found in TRUSS projects:

- Reinforced concrete: Corrosion, strength
- Steel: Corrosion, fatigue
- FRP: High strength, brittle
- Asphalt: Viscoelastic, surface damage

The key properties above must relate material characteristics to structural performance, and deterioration mechanisms should be allowed. Dynamic, mechanical, deterioration-based, electrochemical, fatigue, visual, NDT and geophysics field/lab tests are employed in calibrating these material models. Questions to address in this modelling are: Do you have S-N curves for characterizing fatigue? How variable are corrosion rates? How to characterise a brittle material (i.e., FRP)? What NDT methods to use for concrete?

The time dependant deterioration is specific to each material and deterioration mechanism. Corrosion is discussed as an example of deterioration mechanism. The requirements for corrosion to proceed are explained. Steel is resistant to corrosion when encased in concrete due to the formation of a passive film on the steel surface. For corrosion to occur, this passive film must first be destroyed. The most common cause of corrosion in concrete is chloride ingress. Chlorides enter concrete through a combination of transport mechanisms, including diffusion, absorption and capillary action, with diffusion being the most common transport method. When the chloride ions reach the steel they disrupt the passive layer protecting the steel, the passive layer can be destroyed and corrosion initiated if the chloride concentration was high enough. The latter is the first phase of the corrosion process, i.e., initiation. A second phase is propagation with unchecked continuation of corrosion

Standard highway maintenance practice is to apply de-icing salts to pavements in cold weather. When these salts are applied over a bridge, they dissolve in water to form a chloride rich solution that permeates through the bituminous surface and

gathers over the bridge deck. The other main source of chlorides is marine environments. The chloride profile within a bridge can be measured in the field at any given time.

Module on material modelling

1.1.7 Load modelling

Speaker: Prof Eugene OBrien, University College Dublin
Objective: To establish the worst load combination for a given return period, to determine and calibrate load models and to calculate the characteristic load effect (i.e., structural response for a given level of safety).
Description: Load modelling is discussed using traffic loading on bridges as example. Bridge loading in new bridges is designed for a notional load model specified in the Code of Practice. The notional loading represents worst possible combination of "normal" trucks. This is a very conservative traffic load model that provides for future growth in freight traffic.

Bridge loading in existing bridges need to be much more realistic to avoid premature strengthening or replacement. Hence, site-specific load models can lead to significant cost savings. To develop a traffic load model, it is necessary to collect data on truck weights, frequency of heavy trucks, statistics on gaps between trucks, and on axle spacings, etc (i.e., via a weigh-in-motion system). Having gathered truck weight statistics, Monte Carlo Simulation can be used then to generate typical weights of trucks on a bridge, typical axle spacings, typical weights per axle, etc.

The weights are then converted to load effects such as bending moment at a section, shear force, reaction at support, etc. For each truck scenario, the static load effect is calculated combining loads and influence lines for the load effect under consideration. This is repeated many times (using bootstrap, parametric or semi-parametric fits to measurements). Decades of loading events are generated, and for each day or week simulated, the maximum load effect per day or per week is identified. Then, it is possible to fit a statistical distribution (i.e., Cumulative Distribution Function (CDF)) to the maximum load effects and extrapolate the load effect for an acceptable level of safety, i.e., 1 in 1000 years (known as characteristic static load effect). Fit of CDF to data tends to be very inaccurate in tail region, but probability paper plot rescales the vertical axis, making it linear and more suitable for finding characteristic values. There are three families of statistical extreme value distributions typically used for compliance with available data and extrapolation: Gumbel, Weibull and Frechet.

Finally, a dynamic amplification factor is applied to the characteristic static load effect to estimate the characteristic total load effect. If a notional load model is developed for an entire road network (as opposed to a single bridge), the characteristic total load effects need to be found for a range of spans, bridge types and load effects. The notional load model would have to give approximately the same load effects as the characteristic total load effects. If probability of failure was sought, it is needed to combine a probability distribution for resistance with the distributions of load effect to get the probability of load effect exceeding resistance.

Module on load modelling

1.1.8 Overview of fault diagnostics methods-part one

Speaker: Dr Rasa Remenyte-Prescott, University of Nottingham
Objective: To understand the aim and benefit of fault diagnostic methods and the use of Bayesian Belief Networks (BBNs) for identifying faults and its causes in a structure.
Description: The aim of system fault diagnosis is to recognise when a fault exists on a system and to identify its causes for reducing system unavailability and increasing system safety.
BBNs are probabilistic graphical models ideally suited for modelling the causal relations between faults and symptoms. The prior (initial) probability of an event can be updated following an observation (evidence) about the system state. The posterior (updated) probability of component failures is a measure of which components have caused the observed symptoms.

BBNs can model the uncertainty of relationships among random variables using the failure logic of the system. They consist of nodes, representing variables of interest (e.g. the occurrence of an event or a system component), and links joining the nodes, representing causal relations among the variables. Nodes can be root (without a parent node) or child. The probabilities of a root node being in each state is given by prior probabilities. The probability of any child node is calculated (1) using the law of total probability; (2) applying the chain rule to express each term using conditional probabilities; (3) simplifying each term according to the connections within the BBN, and (4) taking the probabilities from Conditional Probability Tables (CPTs). Node probability can be then updated using the Bayes' theorem.

Examples are provided to illustrate how BBNs are implemented for fault diagnosis. The steps include the probability update of each root node as per above, followed by the calculation of the probability of 'true' state of each root node with evidence about the state of a child node, usually fault

occurrence. If the root node was not related to the node with evidence, its prior probability does not change, therefore, the calculations for that root node can be omitted. Finally, the probability of an individual component causing system failure can be used to rank the causes.

Module on overview of fault diagnostic methods - part I

1.1.9 Overview of fault diagnostics methods-part two

Speaker: Dr Marius Vileiniskis, University of Nottingham
Objective: To understand the application of One Class Support Vector Machines for identifying faults prior to failure.
Description: The aim of "fault diagnostic techniques – data based" is to identify deteriorating conditions prior to failure. Here, fault detection is treated as a classification problem. This lecture is focused on the data drive method known as One Class Support Vector Machines (OCSVM).

In terms of system fault detection, OCSVM is trained to learn the behaviour of a system under normal conditions to identify abnormal behaviour of the system. Trained OCSVM is used to classify the new data as falling into either normal (system with no failures) or abnormal class (system with a failure present). OCSVM is used to identify a highly represented class in order to detect a small amount of abnormalities.

The main idea of OCSVM is to find the boundary of a surface in a feature space that "covers" the most of the training data using a small fraction of the training data (support vectors). Current applications of OCSVM are reviewed and a real-case application to railway point machines (Network Rail) is used to explain the implementation of OCSVM to identify faults. The benefits are to reduce disruptions and to increase safety in railway networks moving towards preventive (instead of corrective) maintenance and a more convenient scheduling of maintenance works.

Module on overview of fault diagnostic methods - part II

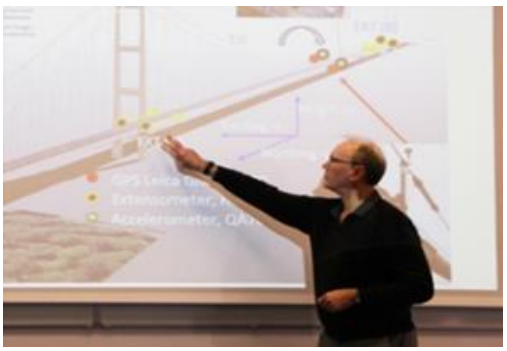
1.1.10 Structural health monitoring

Speaker: Prof James Brownjohn, Full Scale Dynamics
Objective: To understand what Structural Health is, the origin and evolution of Structural Health Monitoring (SHM) systems and the requisites of a SHM system (diagnosis and prognosis). Also, to become aware of Structural Identification technologies and what the future brings for SHM systems.
Description: SHM is a continuous identification of a physical or parametric model of a structure using time-dependent data. The signals used in SHM are derived not only from vibrations, and it's not all about detecting damage.

The start of Civil SHM can be related to the Dale Dyke dam failure in 1864 (Sheffield, UK) that led to The Reservoir Act, which gives a supervising engineer legal responsibility for continual surveillance including keeping and interpretation of operational data. History of SHM for major bridges goes back at least 70 years as a result of seismic concerns (I.e., measurements at Golden Gate Bridge). A program of bridge vibration studies followed the Tacoma Narrows collapse. In offshore structures, civil SHM is mostly focused on piles.

While automotive and aerospace industries feature health/performance monitoring with real-time diagnosis to provide condition-based maintenance and/or immediate decision support avoiding the need for costly inspections, SHM challenges with civil infrastructure are actually greater with each structure being a prototype. Civil SHM seeks both diagnosis (Prove structural fitness for purpose; check novel systems of construction/structural forms; validate structural modifications & mitigation measures; track structural loads/overloads/extreme responses; evaluate 'serviceability'; provide a feedback loop to design and loading codes; detect 'damage'?) and prognosis (Assess structural safety after trauma; track long term degradation to aid maintenance decisions; provide warning of impending failure?).

Civil SHM comprises automated, on-line elements (Long term monitoring – sensors and data -) and user-driven, usually off-line elements (Condition assessment – testing and model validation/updating -). A number of active SHM systems are reviewed including Maentwrog Dam (North Wales), Tsing Ma, Hong Kong (Fugro), Donghai Bridge, China (National Instruments), Rion Antirion Bridge, Greece (Advitam) and Humber Bridge (UK). Structural identification technologies with updated FE modelling are also explained using the Tamar Bridge (UK) as example. It is seen how data-driven SHM detects subtle performance anomalies via mathematical time series analysis series of response parameters. Finally, vision systems in the Humber and Tamar bridges are discussed, and the following question is posed: "Measuring without sensors?"



Module on structural health monitoring

COMMUNICATION/TRANSFERABLE SKILLS MODULES

Transferable/Communication modules provided fellows with a clear idea on how to build a research plan, and how to improve their presentation skills towards their first public appearances with TRUSS.

1.1.11 Planning your research

Speaker: Alison Johnson, University of Nottingham
Objective: To encourage fellows to consider some of the common issues that early stage researchers face. To help them to acquire the core skills and the knowledge required to plan and manage a research project and to explore approaches to managing time effectively.
Description: Key questions that should be asked by a researcher were addressed. Then, fellows were divided into groups to analyse the skills of an effective researcher.
Basics of Project Management were explained, which included key questions, stages, tools for seeing "the big picture" and managing risks. Finally, planning tips were given together with advice for time management.


Module on planning your research

1.1.12 Presentation skills

Speaker: Alison Johnson, University of Nottingham
Objective: To share top presenting tips and to help researchers to consider, discuss and explore some of the skills involved in preparing an effective presentation and to meet the needs of different audiences.
Description: ESRs, divided in teams, analysed what makes a presentation good and what makes them feel uncomfortable when presenting in front of an audience.
Aspects of the process of preparing a presentation were explained such as considering the audience, preparing audio/visual aids, scripts, practice, venue and equipment available, structure of slides, among others. Some tips were given for handling questions, controlling nerves and using appropriate language.

In order to demonstrate the importance of a shared context to deliver effective explanations, an exercise in pairs was carried out. One person was the 'explainer' and the other was the 'listener'. Fellows sat back to back with the listener facing the back of the room. The 'explainer' was given a simple diagrammatic picture. The aim is to explain that picture in such a way that the 'listener' can reproduce the picture.



Module on presentation skills

TEAM ACTIVITIES

There were two types of team activities:

- Innovation workshop module consisting of working together in teams to solve a case study prepared by Professors Eugene OBrien (University College Dublin) and James Brownjohn (Full Scale Dynamics). The case study was provided on the Monday afternoon. The fellows were organised in teams to prepare a solution and present their proposal at the end of the week.
- A cultural visit organised by University of Nottingham, aimed to form powerful relationships supporting each other's professional growth.

1.1.13 Innovation workshop

Activity: Case Study on Bridge Safety Assessment, provided by Prof Eugene OBrien (UCD) and Prof James Brownjohn (FSDL)
Objective: The aim of this workshop is helping fellows to:

- Formulate solutions to open-ended problems in structural safety
- Learn to work as a team
- Develop an understanding of the principle mechanisms through which structures carry load and transfer loads through elements in to the ground and how to assess their safety
- Consider the wider social and environmental aspects and identify risks associated with their schemes
- Demonstrate effective presentation skills

Description: The case study problem simulates a situation where multi-disciplinary team work must be efficient to solve a real-world ill-conditioned problem. As part of the experience, fellows acknowledge the benefits of learning to work as a team. The format is that a brief is issued to the ESRs on Monday whereby three teams of ESRs (4 ESRs per team) compile their solutions during the week and present them to their peers and consortium experts on Friday in a "question and answers" type, interruptible presentation format. Prof OBrien was available on the Monday afternoon to introduce the case study and answer any queries via video call. Time was allocated during the week (Wednesday afternoon and Thursday from 11 to 5 pm) to facilitate team work towards the solution. Prior to the training week, ESRs had been introduced to google collaborative tools, so they could build this presentation working together and simultaneously using google slides during the week.

They finally presented their solutions on Friday afternoon. Presentations were in an interruptible forum with participation of all team members, and the presentation material had to contain sufficient information to fully justify their decisions. Overly complex visual aids (animation, etc.) were to be avoided – this was an interactive discussion/critique of what fellows are proposing and of the judges' opinions of the merits and

shortcomings of the proposed solutions. Each team had about 30 minutes each including questions by Professors OBrien and Brownjohn who acted as judges in an "X-factor" style. Finally, a team was appointed as winner, and Prof Brownjohn, who had been involved in the monitoring of the bridge subject of the case study, explained what really happened and the solution adopted in practise.

The teams were selected to include at least one fellow with specific knowledge on the problem in hand, to be sufficiently large to provide sufficient pool of knowledge, experience and views to promote the active participation of all team members, but small enough to prevent inhibition of active participation of everyone. They were also chosen to be as heterogeneous and diverse as possible to facilitate interaction, group learning, achievement, team role allocation and mutual beneficial across abilities. Table 2 shows the team composition.

Table 2 - Team composition

Team 1	**Team 2**	**Team 3**
Giulia Milana	Sofia Antonopoulou	Barbara Heitner
Matteo Vagnoli	Federico Perrotta	JJ Moughty
Daniel Martinez	António Barrias	Siyuan Chen
Rui Teixeira	Farhad Huseynov	Alberto González

Given the nature of the learning which is required in this workshop (application rather than acquisition), the problem is well-defined following the usual problem based learning definition. It is relatively open-ended and based on a realistic project to encourage diversification and contribute to a real-world feel. The brief on the case study specified that:

This is a major bridge in a bottleneck location that is scheduled to be replaced in 10 years' time. It has deteriorated and the client is concerned about its safety in the interim period until it is replaced. Your brief is to advise the client on the following:

- *Specify a series of tests to assist in establishing the safety of the bridge*
- *Recommend a programme of analyses/studies and*
- *Propose a system of sensors for ongoing monitoring.*
- *All of this should take account of the client's 'tight' budgetary situation and keep costs at a sensible level.*

Together with the brief, fellows were provided with links to a wealth of information containing reports, papers, drawings and photos published about the bridge.

While traditional teaching tell students what to learn, the principle behind the case study proposed here is to let students identify what to learn by introducing them a problem first, and then let them work towards the understanding of its resolution. Such an approach allows developing specialist knowledge and key transferable skills for work and social life, i.e., students are able to adapt more easily to changeable scenarios than with a traditional learning method where the learning material is explicitly provided to the student via lectures. Peer and deep learning is also promoted (knowledge is constructed by independent study and discussion with peers). It must be noted that is not only problem solving capacities that are enhanced, but also communication skills and interpersonal skills. This way, students get prepared for lifelong learning deemed to be essential in an era of continuous technological changes and access to practically unlimited sources of information. Even more, because the concepts are learnt by the student as a discovery, the retention rate will be significantly higher than when it is verbally transmitted by a lecturer.

Module on case study

1.1.14 Team building activity

Activity: Visit to Chatsworth
Objective: To promote team cohesion by facilitating ESRs a relaxing and informal environment where to know each other.
Description: The activity was held in Chatsworth House located in Bakewell, Derbyshire, United Kingdom. Fellows were accompanied by the Project Manager, Loreto Manriquez. The team activity held in Bakewell aimed to build relationships between ESRs that contributed to high team performance and cooperative learning in TRUSS.

There are different types of groups depending on their performance: pseudo-teams, working groups, potential teams, real teams and high-performance teams. In the working group, the individual contributions are added together without building on one another. In the pseudo-team, there are lots of team talk provided by the challenge or the impetus of an individual but proper organization is missing and performance is the poorest of all groups. In the potential team, there is not discipline or clear goals resulting in a performance similar to most of working groups. In the real team, all members share common goals, they have complementary skills and hold mutually accountable for their results. Finally, in the high performance team, members form powerful relationships with a very strong personal commitment to one another's personal growth and development (source: Katzenbach, Jon R. 1993.

The wisdom of teams: Creating the high-performance organization: Harvard Business Press).


Team building activity

RESEARCH SEMINARS

Speakers: All ESRs.
Objective: Research Seminars (presentations by fellows on their individual research projects) followed by face-to-face doctoral studies panel meetings that allowed fellows to get feedback from the consortium for their Research and Personal Career development plans.
Description: These seminars are interactive presentations by ESRs that prepare them to present their own work at other national and international events. Here, presentations are confined to TRUSS partners and researchers local to the host venue who wished to attend. In this first training week, the theme of each presentation has been mostly around the research plan and literature review to date. These research plans are described in detail in deliverable 'D3.2 - PCDPs by all ESRs' due in January 2016. After presentations, each ESR was called on an individual basis for face-to-face meetings with his/her DSP to discuss the PCDP.

Reliability of concrete structures reinforced with braided FRP by ESR1

Reduction of uncertainty in design of free standing nuclear spent fuel rack by ESR3

Probabilistic optimisation of the design of offshore wind turbine towers by ESR4

Residual life assessment and management of ship unloaders by ESR6

Railway Weigh-In-Motion for bridge safety by ESR7

Probabilistic modelling of bridge damage based on damage indicators by ESR8

Railway bridge condition monitoring and fault diagnostics by ESR9

Assessment of bridge condition and safety based on measured vibration level by ESR10

Development of optical fibre distributed sensing for SHM of bridges and large scale structures by ESR11

Bridge damage detection using an instrumented road vehicle by ESR12

Using truck sensors for road pavement performance investigation by ESR13

Reduction of uncertainty through regularized, automated inspection by ESR14

Module on research seminars

1.2 TRAINING WEEK 2

The 2nd TRUSS ITN training week was held in Universitat Politécnica de Catalunya (UPC) (Spain) from Monday 16th to Friday 20th January 2017.

Modules for the training week are classified into core research modules, specialist research modules, team activities and research seminars. Table 3 gives the distribution and module titles for this training week. The contents aim to complement learning acquired by ESRs during their work experience in TRUSS, and in particular the 1st training week held at University of Nottingham (UK, 30th November to 4th December 2015).

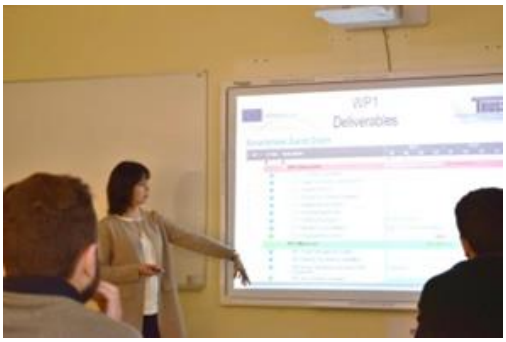
All fourteen ESRs attended the training week. Additionally, four postgraduate researchers and five lecturers external to TRUSS attended modules of the training week. The following subsections give a detailed description of the syllabus for each training module. Lecture notes for all modules were made available to ESRs via google drive. Some of this info is also available at TRUSS website. At the end of the week, answers to a confidential questionnaire were gathered from ESRs to identify those modules found more useful for the project and for their future career, and to propose new modules to cover their needs or a follow-up to existing ones in a future training event.

Table 3 – Modules imparted in training week 2

Type of Module	Name of Module	No. hours
Project Progress	Update on project progress	1
Core Research Modules	Vulnerability and Risk Assessment	1
	Uncertainty Quantification and propagation for sensitivity or reliability purpose	2
	Practical Reliability Engineering – Case Studies	2
	Survival Analysis and Discrete Event Simulation applied to Structural Reliability	2
Specialist Research Modules	Advanced Finite Element Modelling	1
	Multi-Level Monte Carlo Methods for stochastic analysis and robust optimum design	1
	Reducing Uncertainty in Structural Safety through Static Non Destructive Tests	1
	Workshop on Observability Techniques for Uncertainty Reduction	2
	Reducing uncertainty through the Structured Expert Elicitation: justification and methodology	1
Communication/ transferable Skills Modules	Knowledge management: The path to innovation	1
	Responsible conduct in research and innovation	2
Team Activities	Cultural and technical visit to Sagrada Familia and Gaudi´s background on architecture and engineering	7
Research Seminars	Presentations by Early Stage Researchers on their research and consortium/DSP feedback	3
	Total Hours	27

1.2.1 Update on project progress

Speaker: Loreto Manríquez, Project Manager (PM).
Objective: To give ESRs an update on the progress of the project and forthcoming activities.
Description: TRUSS achievements and progress in all Work Packages are presented to the ESRs. ESRs are reminded on the importance of keeping the info on training, research and dissemination in their individual sheets of the Project Management System (PMS) complete, accurate and up to date. They are informed of changes introduced in the individual sheets to facilitate consistency in the data gathered from the ESRs. ESRs are explained how the information required in the PMS is transferred into the reports for the European Commission.



Module on WP progress

CORE RESEARCH MODULES

Core research modules build on modules provided at the 1st training week in UNOTT where basics of "Methods of Safety Quantification", "Reliability Analysis" and "Life Cycle Assessment" were covered. Four reliability topics with advanced statistical concepts are the focus of the 2nd training week: "Vulnerability and risk assessment", "Uncertainty Quantification and Propagation for Sensitivity or Reliability Purpose", "Practical Reliability Engineering – Case Studies" and "Survival Analysis and Discrete Event Simulation applied to Structural Reliability".

1.2.2 Vulnerability and risk assessment

Speaker: Prof Alex Barbat, Universitat Politècnica de Catalunya
Objective: Vulnerability and risk assessment is discussed using the context of the susceptibility of buildings to suffer seismic damage as basis. The seismic vulnerability and risk of buildings and urban areas is treated from intuition to probabilistic evaluation.
Description: Case studies include the Computer Centre of the Telecommunication Ministry in Bucharest (Romania) in 1977, Le Corbusier, Domino House in 1915**,** and structural failures during the earthquake in Lorca (Spain) on 11th May 2011. Risk is a probabilistic concept => the use of probabilistic risk assessment models is not optional. Damage can be assessed by plotting a vulnerability curve with mean damage index in the vertical axis and peak ground acceleration in the horizontal axis. For this purpose, structural properties such as yielding strength of steel are treated as random variables and modelled via cumulative density functions. The seismic demand is modelled via spectral acceleration (g) versus period (s) graphs. Mean vulnerability curves (DI-PGA) and associated uncertainties (standard deviation of DI-PGA) can then be built. Concepts such as the seismic intensity exceedance rate, intensity parameter, return period of the earthquake, hazard curve (exceedance rate of the intensity versus seismic intensity), average annual loss are introduced.

Vulnerability functions, hazard curves and loss related to long return periods are reviewed for the case of an earthquake in Lorca. The concept of mean damage ratio for a single hazard scenario is explained. Then, it is shown how simulated damage resembles the observed damage in % of buildings for Lorca in the categories: no damage, habitable, non-structural damage (usable after reparation), structural damage (currently not usable) and demolition order (severe structural damage). It is concluded that observed and simulated damage results have the same order of magnitude and huge uncertainties.

Module on vulnerability and risk assessment

1.2.3 Uncertainty quantification and propagation for sensitivity or reliability purpose

Speaker: Dr Thierry Yalamas, Phimeca Engineering
Objective: The objective is to introduce the general methodology for uncertainty propagation, the methods for sensitivity and reliability analysis, their application to a civil engineering context and the software tools available to carry out this analysis.
Description: Three steps are distinguished within uncertainty methodology.

- Step A is *the physical model*, which include the mathematical modelling of the physic (analytical model, numerical model –FEM- and response –surrogate-model), quantity of interest determination and criteria (deterministic –max or min-, probabilistic –dispersion, or probability to exceed a threshold-, or no criteria –ranking of input parameter-).
- Step B is *the uncertainty model*, which deals with the experimental data available (probability density estimation, statistical validation tests, correlation estimations, etc.) or no specific data available (expert based probabilistic definition for each parameter).
- Step C is *the uncertainty propagation* that transforms the physical reality into a reliability analysis (probability of failure) following Step A (model and failure scenario) and Step B (probabilistic model).

Monte Carlo simulation, Quadrature methods and Quadratic Cumul methods are discussed as methods of uncertainty propagation for sensitivity analysis. Monte Carlo method is the most natural and it consists of generating a sample of the input, computing the output for each set of input parameters and evaluating statistical moments on the output sample. Then a descriptive analysis or inferential analysis can be performed on the output. The inconvenience of Monte Carlo can be the requirements in computational resources (many calls to the physical model). The Quadrature method is a numerical problem that solves statistical moments under integral form by means of a discrete sum. Statistical moments can be obtained with a relatively small number of calls to the physical model for a limited number of input parameters. The Quadratic Cumul approximation is based on Taylor series expansion. It only requires the model response and partial derivatives of the response at the mean, but it is impossible to quantify the error due to the approximation of the model.

The use of Monte Carlo simulation, approximation methods (FORM, SORM) and advanced simulation methods (importance sampling, directional sampling, subset sampling, and metamodeling) as methods of uncertainty propagation for reliability assessment are also reviewed. Finally, a practical demonstration is carried out using the graphical capabilities of Phimeca software.

Module on uncertainty quantification and propagation for sensitivity or reliability purpose

1.2.4 Practical reliability engineering – case studies

Speaker: Prof Alan O'Connor, Trinity College Dublin
Objective: To demonstrate the significant cost savings via probabilistic methods that can prevent a structure from unnecessary replacement/rehabilitation/repairs by demonstrating the required structural safety is met.
Description: The formal guidelines for probabilistic-based assessment of highway structures by the Danish Roads Directorate is presented as reference. A deterministic approach should be applied first. Probabilistic assessment is recommended only if the deterministic approach establishes that repair, rehabilitation or replacement are needed. Probabilistic assessment involves statistical modelling of load and resistance parameters obtained through on-site measurements and from as-built drawings. Comparison of the probability of failure with that specified by legal requirements is used to validate the safety of the structure. The requirements at the ultimate limit state (i.e., Probability of failure or safety index, β) are specified with reference to failure types and failure consequences:

- *Failure Type I* – Ductile failure with remaining capacity
- *Failure Type II* – Ductile failure without remaining capacity
- *Failure Type III* – Brittle failure

In addition to determination of the value of β, a sensitivity analysis should be performed to determine the sensitivity of β to variations in the parameters describing the stochastic variables modelled in the analysis. The latter allows identifying how small changes in the mean and standard deviations of the random variables affect the safety index.

The presentations go over a number of Danish and Swedish case studies where probabilistic methods have been employed. Results of deterministic results are compared to results of probability-based assessment for 11 bridges, with a total saving in costs of €40,4 million. The probability-based assessment of the Storstroem bridge (Denmark) and the Bergeforsen railway bridge (Sweden) are analysed in detail. While the former is a 3.2 km long bridge exposed to a marine environment with serious deterioration on both the concrete and the reinforcement, the latter is a 168 m single track bridge. Finally, costs of consultant fee, contractor fee, project management and total cost are compared for the three phases of the project:
(1) Deterministic assessment;

(2) Advanced deterministic assessment incorporating updated structural models and rain flow analysis for fatigue analysis, and
(3) Probability based assessment performed at critical locations determined in phase (2).

From the examples provided in this lecture, it is clear that the cost savings resulting from probabilistic assessment have been substantial and that the uncertainty on future maintenance needs have been significantly reduced thereby making overall long-term budgets more accurate and facilitating optimisation of available resources.

Module on practical reliability engineering-case studies

1.2.5 Survival and discrete event simulation applied to structure reliability

Speaker: Prof. Carles Serrat, Universitat Politècnica de Catalunya
Objective: To review basic concepts on survival function, distribution function probability function, hazard function, cumulative hazard function and mean residual lifetime. Focus is placed upon most common parametric models such as Exponential, Weibull, Lognormal and Gamma models. Censoring, likelihood function, truncation and competing risks are also covered.
Description: The survival or reliability function is defined as the probability of an individual surviving beyond time *t*. The distribution function is defined as the probability of an individual dies before time *t*. Types of failures:

(i) *Increasing hazard function*: Populations with a natural aging or wear. The distribution is called IFR (Increasing Failure Rate);
(ii) *Constant hazard function*: Populations with no aging. The resulting distribution is the exponential;
(iii) *Decreasing hazard function*: Populations with a very early likelihood of failure. Individuals get stronger with time. For example, some electronic components in solid state or patients after a transplant. The distribution is called DFR (Decreasing Failure Rate). We find a DFR pattern at the beginning of life of any living being;
(iv) *Hazard function with bathtub shape*: decreasing at the beginning, constant during a long period of time and increasing at the end of life. Appropriated as a model for populations that are followed from birth. A lot of mortality data follows this kind of curves since at the beginning death are due to childhood disease, later on the failure rate keeps stable and finally we get an increasing failure due to the population aging;
(v) *Hazard function with hump shape*: it grows at the beginning and decreases after a period of time. Appropriated as a survival model after surgery since at the beginning there is a high risk of death due to infections and possible haemorrhages, and it decreases as the patient recovers.

In literature about failure times, some parametric models have been used repeatedly. The exponential or Weibull models, for example, are commonly used due to the simplified way that probabilities of distribution tails are expressed, and thus the simplicity of the survival and the hazard function. The lognormal and gamma models, although being less convenient due to computational difficulties, are also often applied. The most commonly used models in survival are Exponential, Weibull, Log-normal, Gamma, Log-logistic and Gompertz. In order to decide if any distribution families that we have studied is appropriated for our problem and our data, we can take into account the following points:

- its technical convenience to the statistical inference,
- the reasonable simplicity of the expressions of its survival or hazard function,
- the good behaviour of the hazard function,
- the value of the coefficient of variation and its analysis with respect to the value 1 as an indicator of exponentiality,
- the representation of the asymmetry taking into account that is equal to 2 in an exponential model, 0 in a normal model and 2/k in a gamma family,
- the behaviour of the survival function for large values of time, and
- the possible connections with a failure model.

On the other hand, it is important to realize that in some cases we will not have enough data to validate the chosen law. In that cases it is very important the behaviour of the model for early values of time - for example, in industrial applications when studying guarantee periods-, and for large values of time - in many medical applications we will be more interested in the right tail of the distribution, corresponding to large survival times-.

Data is collected within a time window. Events occurring outside this time window are not observed. Individual times-to-event can be observed leading to an exact observation or not observed leading to a censored observation. We refer to censoring when we only know that the time to event has occurred in a certain interval of time. Censored data can be right-censored (Type I, Type II, Random), left-censored, interval-censored and doubly-censored. The likelihood function is written as the product of the contribution of each individual. The effect of the truncation's condition is to filter the presence of certain individuals in such a way that the investigators are not aware of their existence. Hence, whatever inference is conditioned to that condition:

- It can be to the left when only individuals of a certain age enter the study (These are known as delayed entries),
- It can be to the right when only those individuals who have had the event are observed (That is, only those patients that fail are included in the study. For example, in a study about mortality which is only based on death certificates).

Sometimes individuals are at risk of other events which don't allow to observe the event of interest:

- Failures due to other causes (competing risks analysis) (i.e., death due to causes which are different from the one we are interested in, or Secondary failure causing inactivity of a machine);
- Survival is modelled via the cause-specific hazard function. A few examples are provided.

Module on survival analysis and discrete event simulation applied to structural reliability

SPECIALIST RESEARCH MODULES

A module on "Advanced Finite Element Modelling" explains how to model a structure using finite elements and it serves to complement specialist modules on load and material modelling delivered in UNOTT during the 1st week. While structural health monitoring methods based on dynamic measurements and fault diagnostic methods to characterize damage or structural parameters were also covered in UNOTT, the following alternative/complementary methods are discussed during the 2nd week: Monte-Carlo (MC), Multi-Level Monte-Carlo (MLMC), Genetic Algorithms (GA), the Observability Method (OM) (applied to non-destructive static tests) and expert elicitation (when data is insufficient and expert judgment is needed).

1.2.6 Advanced finite element modelling

Speaker: Dr Salam Al-Sabah, Ove ARUP and Partners, Ireland
Objective: To understand the evolution of finite element modelling from its origins to our time, and the limitations of different types of elements.
Description: The Finite Element (FE) method is a numerical technique to solve differential equations. These equations date back to the 17th century. There are closed forms solutions for simple differential equations, but most real life applications require more complex Partial Differential Equations, that usually do not have a closed form solution. Numerical solutions to this problem are reviewed historically.

- In the 1920-40's: Finite difference, lattice of 1D bars, model 3D, square elements, variational forms, flexibility and stiffness, energy principle for matrix methods, the triangular plate element.
- In the 1950's: the birth of finite element modelling, matrix analysis software, the IBM computer and Fortran. In the 1960's: isoparametric formulation and applications.
- In the 1960's-70's: non-linear elements (geometric, material), plate bending element (Kirchhoff-Germain), conforming elements (2nd order diff. equation – C^0 element, 4th order diff. eqn – C^1 element), high order 3D elements, commercial software, mathematical foundation and the arc-length method,
- In the 1980-90's: fluid mechanics, wide applications due to integration of CAD/CAE (automated mesh generation), graphical display of analysis results and powerful and low cost computers and equation solver (Gauss-Jordan, banded, skyline, sparse).
- In the 2000's: design optimization, nonlinear analysis, better CAD/CAE integration, parallel processing, more GUI, more integrated analysis/design environment, open source FE packages.

Module on advanced finite element modelling

Other topics covered included:

- Element types: point, line, area (plane stress-strain, shell), volume (brick).
- Advanced analysis: Multiphysics (stress analysis, dynamics, heat transfer, fluid flow, convection-diffusion, electromagnetism), fire, topology optimisation, parametric analysis-design-drafting, adaptive mesh refinement, more on material constitutive relations, infinite elements, extended elements, finite volume method, boundary element method, mesh-free methods, etc.

1.2.7 Multi-level Montecarlo methods for stochastic analysis and robust optimum design

Speaker: Prof Gabriel Bugeda, Universitat Politècnica de Catalunya
Objective: To gather an understanding on how to apply Monte-Carlo (MC) methods, Multi-Level Monte Carlo (MLMC) and Genetic Algorithms (GA) to reduce uncertainty.
Description: Traditional design optimization tools are based on deterministic analysis of each design assuming that the values of all the parameters of the problem definition are well known and fixed. Reality is not like that and there are many parameters with uncertainties in their values. Typically, in solid mechanics real problems there are uncertainties in the geometry, the mechanical properties, the loading conditions, etc. In aeronautics, typical uncertainties affect the Mach number, the angle of attack and also the geometry. Parameters with uncertainties are normally characterised through a probabilistic density function. When a deterministic optimal design is used under off design conditions its performance can decrease a lot unless robustness be introduced in the design process.

Analysis with uncertainties is an important aspect for Robust Design. Methods for analysis with uncertainties can be classified within three categories:

- *Statistical methods* (multi-point/DOE, Monte-Carlo, Multi-Level MC),
- *Intrusive methods* (Polynomical Chaos method, Perturbation method, Stochastic Galerkin, Fuzzy FE method) and
- *Non-intrusive methods* (Probabilistic collocation, Stochastic collocation).

MC is an easy to implement method that generates sampling cases based on the probability density function of each parameter with uncertainties. MC needs a big number of sampling points for a good statistical representation of the stochastic solution (especially big if the number of parameters with uncertainties is big), and a good level of resolution of each deterministic analysis which makes it expensive.

MLMC combines a big number of analysis with a low level of resolution with a small number of analysis with a high level of resolution making the total cost much lower than with classical MC. MLMC is cheaper than MC, providing a better accuracy in mean and variance values. Any kind of discretization is possible with MLMC, mesh is the most relevant.

GA are metaheuristic multi-purpose and random algorithms. Although slower compared to gradient based, they enable to overcome unknown behaviour of the objective functions (discontinuities, non-derivability). GA are always associated to a higher computational cost, compared to other optimization methods. Black box strategy works perfectly well and simplifies the task.

Module on Multi-Level Monte Carlo methods for stochastic analysis and robust optimum design

1.2.8 Reducing uncertainty in structural safety through static non-destructive tests

Speaker: Prof Jose Turmo, Universitat Politècnica de Catalunya

Objective: To bring awareness on the potential of the Observability Method (OM) for structural system identification purposes.

Description: OM is the first efficient method to solve systems of monomial-ratio equations. A subset of variables is observable when the system of equations implies a unique solution for this subset, even though the remaining variables remain undetermined. The applicability of OM is demonstrated for the case of measurements obtained from a controlled static test. Here, the stiffness matrix multiplied by the displacements leads to the forces applied on the structure. In these systems of equations, there are known and unknown variables. The following issues are faced:

- Non-linear products of coupled variables appear in these multiplications (*linearization*),
- target unknowns (i.e., stiffness) is coupled with deflections (*decoupling process*), and
- observed information not considered (*Recursive process*).

The OM is a parametric approach to deal with these issues. The minimal measurement set can be established via observability trees. Errors increase at the proximities of zones with zero curvature. OM combines a symbolical and a numerical approach that allow obtaining parametric equations of the estimates. The method is shown to be computationally very efficient.

Module on reducing uncertainty in structural safety through static non-destructive tests

1.2.9 Workshop on observability techniques for uncertainty reduction

Speaker: Prof José Antonio Lozano, Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos de la Universidad de Castilla-La Mancha

Objective: The aims of this workshop are understanding: (a) the differences between the direct and the inverse analysis of the stiffness matrix method, (b) how the observability technique is applied, (c) the concept of observability trees and flow, (d) structural system identification of the structure both symbolically and numerically, and (e) future applications on your research field.

Description: Two examples are carried out to demonstrate how the observability technique can be implemented using Matlab. First, a simply supported beam is discretized into three elements. Global stiffness matrix is assembled, deflections to known applied loads are given, and the inertias of these three beams are sought by the observability method. The symbolical analysis and recursive process are discussed. The second example is a two-span bridge, a 2D model with 9 nodes and 8 beam elements. The individual stiffness of all beams and boundary conditions are unkowns. Vertical and horizontal loads are applied, and horizontal and vertical displacements and rotations are measured at certain nodes. There are coupled flexural stiffnesses and couple axial stifnesss. The axial observability tree and the flexural observability tree are employed to obtain all stiffnesses in a recursive process. In the workshop, ESRs are taught to use axial and flexural observability trees to define a measurement set that assures an adequate observability of all axial and flexural stiffnesses. Then, a symbolic approach is empoyed to identify the

parameters uniquely defined (observable) for the measurements calculated by the preceding point and to obtain their parameteric equations. Finally, the ratio between the estimated and the actual stiffness is assessed for each element for different levels of accuracy in the measurements.

Module on workshop on observability techniques for uncertainty reduction

1.2.10 Reducing uncertainty through the structured expert elicitation: justification and methodology

Speaker: Dr Maria Nogal, Trinity College Dublin
Objective: To introduce Expert Elicitation, or the process of synthesis of subjective judgements of experts on a subject where there is uncertainty due to insufficient data because of physical constraints or lack or resources, and "Structured" Expert Elicitation, or the process based on structured protocols to reduce potential sources of bias and error among experts.
Description: The analysis of uncertainty can be addressed under other perspective beyond the frequentist-based probability. Marginal and joint distributions which are expensive or difficult to be measured can be known through the structured expert elicitation.

What can we obtain from the experts? Fuzzy set theory (i.e, ranges for cost and damage level), Semi-Quantitative methods (i.e., ranks for model parameters and risk factors, scoring of the relative importance of factors in a scenario) and Quantitative methods (quantitative estimates, uncertainty distributions, dependence modelling) are reviewed.

Delphi method is a behavioural method that looks for the consensus among experts, who are typically encouraged to interact and share their assessments. Cooke's method is mathematical method that deals with individual assessments and combine them mathematically after their elicitation to yield more accurate results. The Cooke's method for the uncertainty distribution of the random variables is well-developed and widely used. In Cooke's method, calibration measures the statistical likelihood that a set of experimental results statistically correspond with the expert's assessments. Assuming as a null hypothesis that the inter-quantile interval containing the true value for each variable is drawn independently from the probability vector p, the expert's assessment can be treated as a statistical hypothesis, and the p-value can be used as a calibration score. Informativeness considers how concentrated a distribution is. To measure it, the density of the sample distribution provided by the expert e for the quantity i is compared against a background probability density (usually uniform or log uniform distribution) over the extended intrinsic range. The Decision Maker or combination of experts' assessment is carried out by the summation of the experts' assessments of the variables of interest, weighted according the scores obtained.

Dependence modelling and the high potential with a number of applications are explored. Copula is a multivariate probability distribution for which the marginal probability distribution of each variable is uniform. The multivariate Gaussian copula is discussed. In Bayesian networks, each node is associated with a continuous arbitrary invertible distribution function and each parent-child influence is represented as a (conditional) one parameter copula, parameterised in terms of the (conditional) rank correlation. When all copulas in the assignment of a Non-Parametric Bayesian Network correspond to the bivariate normal copula, then a multivariate Gaussian copula with correlation matrix is obtained. D-calibration measures the distance between a "seed" correlation matrix and the correlation matrix obtained based on experts' opinion. An example to assess the vulnerability of a traffic system through numerical indicators is carried out.

Module on reducing uncertainty through the structured expert elicitation: justification and methodology

COMMUNICATION/TRANSFERABLE SKILLS MODULES

The module "Knowledge Management: The Path to Innovation" is provided by the Head of the relevant Department in a TRUSS industrial partner. This module builds on the basics for project management that were provided in the module "Planning your Research" at the 1st training week. ESRs also become aware of a variety of important moral and social values promoted by research via the module "Responsible Conduct in Research and Innovation".

1.2.11 Knowledge management: The path to innovation

Speaker: Prof Joan Peset, COMSA
Objective: To share with ESRs the significance of Knowledge Management and Innovation, and the experience of working in a specialised Department on this topic.
Description: The Head of Knowledge Management and Innovation Department introduces the topics covered in a research management position. The areas of activity of COMSA in Infrastructure and Engineering, Services and Technology and Concessions and Renewable Energy are explained. Subsidiary companies also make a significant contribution to construction and maintenance works at specific countries. The focus is then placed upon railway infrastructure, which has been the main speciality of the company form its foundation. The service goes from the initial study and project design to the construction and maintenance of railway infrastructures and superstructures, metros and trams, including their operation. In the Department of Knowledge Management

and Innovation, clients/suppliers, academia and business units expertise guide the technological challenges to address. There are a number of key activities within the Department:
(i) *acquiring know-how* (benefiting from work site experience). The strong collaboration between the technical department and the work site permits and easy and quick transfer of knowledge;
(ii) *tools* (technical procedures and IT tools). All the know-how acquired form the work site has to be well managed and stored in order to be applied in the next projects. A great way to gather together this information is creating technical procedures, where not only a description of the works can be found but also output and construction cost rates. Data Bases can offer a great improvement in information accessibility, which contributes to make easier the access and transfer of information;
(iii) *Technical support*. The Technical Dept. gives support to the work site in each step of the project (from the study/ tender process of the project until the reception of the work site). All the innovation and know-how of the Technical Dept. are conveniently applied in order to improve economically and technically the projects;
(iv) *R&D strategy*. Innovation represents nowadays one of the top drivers of growth of a company. Improving construction methods by applying advanced technology enable not only to reduce cost and execution time of the work site, but also helps to reinforce the leader position of the company;
(v) *Lean construction*. The goal is to improve the efficiency of the construction works by eliminating the "waste" (activities with no added value for the client). Building Information Modelling (BIM) is also discussed and a number of ongoing and recently completed projects are reviewed.

Module on knowledge management: The path to innovation

1.2.12 Responsible conduct in research and innovation

Speaker: Prof Jordi Domingo, Universitat Politècnica de Catalunya
Objective: To facilitate the pillars for a responsible conduct in research.
Description: Responsible conduct is not easy to define. It is about ethics … about common accepted rules or behaviour. There is not a single "best way" to undertake research; there are specific ways in different scientific fields. Accepted practices vary from discipline to discipline and even from lab to lab or group to group. Scientific/Professional societies or communities publish codes of conduct. Misconduct is fabrication, falsification or plagiarism in proposing, performing or reviewing research, or in reporting research results. Research misconduct does not include honest error or differences of opinion.

Four responsible conduct pillars can be distinguished:

(a) *Government Regulations*. Definition of what is and is not allowed; penalties;
(b) *Professional Codes*. List of principles; general statements; set a minimum standard; do not imply that all other behaviours are accepted;
(c) *Institutional Policies*. Promotion of good practices; establish definitions for misconduct in research; define procedures for reporting and investigating misconduct; provide protection for whistle-blowers and persons accused of misconduct; Researchers and research institutions bear the primary responsibility for reporting and investigating misconduct; the position that research is a profession and should regulate its own conduct, is strongly supported by most researchers;
(d) *Personal Convictions*. Personal ethics. Institutional policies help to establish a suitable framework to avoid misconduct and to deal with it if necessary, but they do not solve the problem. Personal responsibility is the key factor. In general terms, responsible conduct in research is simply good citizenship applied to professional life. A number of topics including shared values (honesty, accuracy, efficiency and objectivity) and misconduct, authorship, plagiarism, peer review, conflicts of interests, mentoring, collaborative research and data management practices are reviewed.

Module on responsible conduct in research and innovation

TEAM ACTIVITIES

1.2.13 Visit to Sagrada Familia

Activity: Cultural and technical visit to Sagrada Familia and Gaudi´s background on architecture and engineering, organised by Universitat Politècnica de Catalunya.
Objective: To give ESRs and supervisors an overview of the constructions works in the Sagrada Familia guided by an architect involved in the task, and also, to learn about his creator Gaudi from an architectural and engineering points of view. To promote team cohesion and networking between ESRs and UPC/TCD supervisors and lecturers in an informal environment.
Description: Actual and planned construction was showed by architect Serralana. He explained how the construction team have based their work on original 3D models and drawings from Gaudi. He explained how the majority of works are prefabricated on a site outside Barcelona due to space restrictions. The construction of the Passion Facade and the dome of the Sacristy of Passion, the roofs and the meaning of their colours, were discussed in detail. Works on the different towers such as the Evangelists, Virgin Mary and Jesus Christ

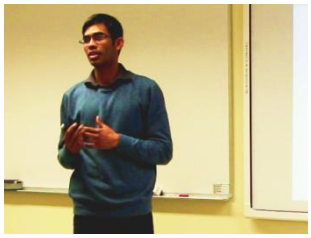
were also described in detail. Building works for the Sagrada Familia are expected to be finished in 9 years.


Architect Jaume Serrallonga gives a talk to TRUSS ESRs and lecturers from UPC and TCD

RESEARCH SEMINARS

Speakers: All ESRs.
Objective: Research Seminars (presentations by fellows on their individual research projects) followed by face-to-face doctoral studies panel meetings that allow fellows to get feedback from the consortium for their Research and Personal Career Development Plans (PCDPs).
Description: These seminars are interactive presentations by ESRs that prepare them to present their own work at national and international events. ESRs took a module on public speaking titled "Presentation Skills" at the 1st training week. Practice makes perfect, however, a proper feedback process is needed, and for that purpose, all presentations in this 2nd training week were fully recorded in video and made available to ESRs internally for self-evaluation and for avoiding mistakes. Here, presentations are confined to TRUSS partners and researchers local to the host venue who wished to attend. In this 2nd training week, the theme of each presentation has been around the research progress and plans following their first year with TRUSS. These research plans are described in detail in the PCDP of January 2017. After presentations, each ESR was called on an individual basis for face-to-face meetings with his/her DSP to discuss the PCDP.

Reliability of concrete structures reinforced with braided FRP by ESR1



Reduction of uncertainty in assessing concrete strength of existing structures by ESR2

Reduction of uncertainty in design of free standing nuclear spent fuel rack by ESR3

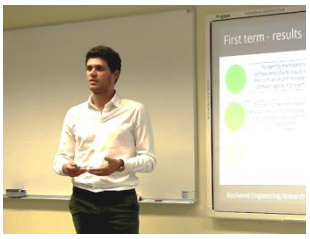
Probabilistic optimisation of the design of offshore wind turbine towers by ESR4

Integrity management of ship structures by ESR5

Residual life assessment and management of ship unloaders by ESR6

Railway Weigh-In-Motion for bridge safety by ESR7

Probabilistic modelling of bridge damage based on damage indicators by ESR8



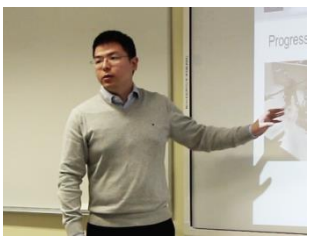
Railway bridge condition monitoring and fault diagnostics by ESR9

Assessment of bridge condition and safety based on measured vibration level by ESR10

Development of optical fibre distributed sensing for SHM of bridges and large scale structures by ESR11

Bridge damage detection using an instrumented vehicle by ESR12

Using truck sensors for road pavement performance investigation by ESR13



Reduction of uncertainty through regularized, automated road inspection by ESR14

Module on research seminars

Further information about the 2nd training week can be found on the TRUSS website (http://trussitn.eu/?p=16122).

1.3 TRAINING WEEK 3

TRUSS third training week was held in University College Dublin and Trinity College Dublin from Monday 15th to Friday 19th January 2018. Modules for the training week are classified into business skills modules, project management course, communication/transferable skills modules, team activities and research seminars. Table 4 gives the distribution and module titles for this training week. The contents aim to complement learning acquired by ESRs during their work experience in TRUSS, and in particular, the 2nd training week held at UPC (Spain).

Table 4 – Modules imparted in training week 3

Type of Module	Name of Module	Time (hrs)
Project Progress	Update on project progress	½
Business Skills Modules	Concept to Commercialization	1
	Stages of Funding. Being Investor Ready	1
	Entrepreneurship and SME Formation	1
	Intellectual Property	1
	Patent Searching	1
	Creating Organisational Structures	1
	Commercialisation and Exploitation	1
Project Management Course	Introduction to Project Management	6
Communication/ transferable Skills Modules	Working with Industry on Collaborative Research Projects	1
	Leadership and People Management	1
	Grant Writing- a Short Guide to Survival and Success	1
	Career Planning for PhD Students	1
	How to Succeed at Interview	1
Team Activities	Cultural Visit Book of Kells and Irish Folklore	1
Research Seminars	Presentations by Early Stage Researchers on their research and consortium/DSP feedback	3
	Total Hours	22 ½

All fourteen ESRs attended the training week. As in previous training weeks, lecture notes for all modules were made available to ESRs via google drive, and at the end of the week, answers to a confidential questionnaire were gathered from ESRs for feedback on the modules provided and on their training needs.

1.3.1 Update on project progress

Speaker: Arturo Gonzalez, Project Coordinator (PC).
Objective: To give ESRs an update on the progress of the project and forthcoming activities.
Description: TRUSS achievements and progress in all Work Packages are presented to the ESRs on the morning of Thursday 18th January. ESRs are reminded on the network-wide activities that are left before completion of the project. Two of the most significant activities are a final workshop and a symposium, together with the deliverables that will be due and requiring their input. Emphasis is placed upon the importance of drawing a clear plan into their PCDPs to timely finish their PhDs. Statistics on the impact of social media and website are reported according to the number of visitors, countries, gender, etc. Info is also provided on the number of views of the fellows' blogs, their most popular tweets/posts, publications, and the training, conferences and outreach activities that have been undertaken within the period from the last meeting in London back in May 2017 to date.


Module on WP progress by PC

BUSINESS SKILLS MODULES

UCD and TCD have imparted training on the entrepreneurial process in the journey from identification of the research innovative idea through to the launch of a successful business. The lectures have defined the stages and processes involved in the creation, capture, management and commercialization of IP. Practical guidelines on how to manage the development and transfer of these intellectual assets to the knowledge economy have been provided. The contents have been grouped under seven main headings: 'Concept to Commercialisation', 'Stages of Funding. Being investor ready', Entrepreneurship & SME Formation', 'Intellectual Property', 'Patent Searching', 'Creating Organisational Structures' and 'Commercialisation and Exploitation'.

1.3.2 Concept to commercialisation

Speaker: Dr. Aidan Quilligan, Clubify
Objective: Commercialisation is the process of managing or running a something principally for financial gain. ESRs are shown how to take ideas and bring them to the market. Concepts from PhD research are applicable here, i.e., problem solving, organisational structures, why and when you are doing a product.
Description: Speaker and ESRs introduce themselves, their company and describe their project, idea and discipline. Sources of innovation can be military (i.e., aircraft, computers, GPS, microwaves, roman roads, etc.), existing commercial enterprises (i.e., Xerox, Apple), curious people (i.e., Da Vinci, Telford, Edison, Tesla, etc.) or research based commercialisation. Curiosity leads to investigation (formal research), based on a hypothesis, often in obscure areas where a path to commercialisation is not initially clear/simple. Significant results (proving your hypothesis) lead to commercialisation opportunities. The stages of product innovation can be classified into:

- Problem solution fit: You have a product that can satisfy the market; you are in a good market; you know exactly who your customer is; why they need your product.
- Product market fit: There is a willingness and desire from customer to have your product; you know how to reach your customers effectively; your economics stack up; usually an inflection point for a company.

- Scale/growth: Broad market demand for your product; marketing and sales ramp up (the more you spend in these areas, the more reward you achieve); the economics of this spend are viable; investors love this stage.

Problem solution drill down includes understanding the various needs of your customer, testing for a good problem to solve, building a good product and a competitive advantage. As a practical exercise, ESRs work on an A4 to describe a business plan based on their TRUSS projects: the problem, the solution, the unique value proposition, the unfair advantage, the customer segments, the cost structure, the key metrics and revenue structure. Then, they share and discuss their plan with the class. Unfair advantage refers to monopolies, first to market, last to market, patents, IP.

Module on concept to commercialisation

1.3.3 Stages of funding. Being investor ready

Speaker: Dr. Aidan Quilligan,
Objective: Investment has the expectation of a return. This session discusses potential sources of funding (friends & family, high net worth individual, VC funds, government backed agencies) and their expectations. Earlier investors want a greater stake.
Description: Differences between University investment and Industry partnerships are highlighted. The J-curve of venture fund investments (internal rates of return versus time that allow distinguishing investment and harvest period) is introduced. The stages of fund raising are:

- Pre-seed (<100k): Idea is still in very early stages; some product-solution iteration; minimal/no market testing; high expectation of failure; accelerators, government organisations, Universities; enough to get an MVP (minimum viable product to market).
- Seed (100k – 2m): Product solution fit is starting to seem likely; some possible product-market fit; enough value for early investors to see the future potential of the product; still high likelihood of failure; angel investors, VC firms, government funding; approx. 10x return on investment.
- Series A: Product-solution fit is tied down; product-market fit is seeming very likely; it is clear to investors that the product has value and market willing to pay for it; some work to do on assessing the market and ability to scale into that market; angle investors (double down), VC firms; approx.. 5-8x return on investment at this stage.
- Series B/C/D/E: Growth; reduced likelihood of failure; lower expected returns; accelerating towards an IPO (Institutional Public Offering).

The session also covers licensing from Universities (spin-out companies; licensing IP; partial or full basis for company; competitive advantage), De-risking (gradually de-risking; more risk -> lower valuation and greater expected return in case of success; Universities -> very high risk, i.e., 95% patents never used; strong argument for investment as risk is reduced) and Investment sources (places to find funding include accelerators, angles, syndicates, VC funds, etc.). ESRs make numerous questions, i.e., how to present a company the problems they have or how can social media be used for commercialisation. The social network depends on the targeted audience, and sometimes emails can be useful for pitching an idea.


Module on stages of funding

1.3.4 Entrepreneurship and SME formation

Speaker: Frank Ward from Frank Ward & Associates
Objective: Entrepreneurship is the process of starting a business or other organization (not only profitable organizations). The concepts of the entrepreneur, how to set up a business, the business model and the business model canvas are brought to the ESR.
Description: The entrepreneur is the person who comes up with an idea, takes a risk and brings all factors together to start a business. The entrepreneur develops a business model, acquires the human and other required resources, and is fully responsible for its success or failure. Some characteristics of the entrepreneur are: confident, decisive, energetic, flexible, future-focused, good communicator, innovative/creative, leader, motivated, realistic, resilient, risk-taker, visionary, etc.

Setting up a business requires to cover many topics such as the idea, the research, finance and cash flow, developing a business model, resources, projecting your business, legal structure, taxation, customer experience, marketing and accounting. The way to extract value from an idea or innovation needs an appropriate business model. The latter seeks to converts ideas or new technology into economic value. In some cases, the innovation rests not with the product or service, but with the business model itself, i.e., a better way of doing things. A business model represents a broad range of aspects of a business (purpose, offerings, strategies, infrastructure, organisational structures, trading practices and operational process and policies) and it is made of numerous components (value proposition, market segment, value chain structure, revenue generation and margins, position in value network, competitive strategy). In three points, the business model essentially…

- … delivers value to customers
- … entices customers to pay for value
- … converts those payments to profit

The business model is done via a business model canvas. The canvas consists of just one page with sub-frames that answer: Who will help you? (key partners) How do you do it? (key activities) What do you need? (key resources) What do you do (you start here)? (value proposition) How do you interact? (customer relationships) How do you reach them? (distribution channels) Who do you help? (customer segments) What will it cost? (cost structure) How much will you make? (revenue streams). The canvas is updated at least once a year, probably more frequently.

Module on entrepreneurship and SME foundation

1.3.5 Intellectual property

Speaker: Frank Ward from Frank Ward & Associates
Objective: To teach ESRs how to protect their ideas via Intellectual Property (IP), their Intellectual Property Rights (IPR), the IPR protection, profile cases and legal mechanisms. This is of increasing importance, especially in this digital age, where sharing and reproduction is so easy and prevalent.
Description: Property in IP refers to idea, invention or process, that derives from the work of the mind or intellect. IPR is the right to the product of your mind to be recognized by national and international laws. Recognition of IPR is intended for encouraging the creation of IP and for paying associated costs, including R&D. A number of profile cases (Napster, Rubik's cube, Adidas, Barbie, movie, etc…) are reviewed.

The main purpose of legal mechanisms is to encourage the creation of a wide variety of intellectual goods. To achieve this, the law gives people and business property rights to the information and intellectual goods they create, usually for a limited period of time. Because they can profit from them, this gives economic incentive for their creation. There are a number of categories for legal protection: patents, trademark, registered design, copyright and others.

A patent confers upon its holder, for a limited period, the right to exclude others from exploiting the patent invention, except with the consent of the owner. It needs to be registered in each country where you are going to make business in order to protect significant markets, i.e, patents are territorial. They can be used by the owner and/or assigned, transferred, licensed to other parties. They have a maximum life span of 20 years and annual renewal fees are required to maintain the patent in force. In order to be eligible for a patent, it must be new, have an inventive step that it is not obvious to someone with knowledge and experience in the subject, and be capable of being used in some kind of industry.

A trademark (TM for trademark or R for registered trademark) refers to any sign of being represented graphically which is capable of distinguishing the goods or services of one undertaking from those of other undertakings. A trademark can consist of words, designs, logos, letters, numerals or the shape of goods or of their packaging, or of other signs or indications. A registered trademark has more protection than a patent. An unregistered trademark may be protected by common law, but only within the geographical area where it has been used or in areas into which may be reasonably expected to expand.

A registered design is a form of industrial property. Design protection is territorial. Some aspects of the design may be protected by copyright. In order to register a design, it must be new (no identical design having made public) and have individual character (overall impression differs from that produced on users by any earlier design). The design can become synonymous with the company behind it.

Copyright protects the form of the expression of the ideas, not the ideas itself. Copyright can be original literature, sound recordings, typographical, computer programme, original databases, etc. Copyright is owned by the author, i.e., the person who creates the work, who has the right to prohibit or authorise others to copy, perform, make available or make adaptation of the work.

Other legal mechanisms include Non-Disclosure Non Circumvention Agreements (NDNCA's), which are legally binding agreements entered between parties at the outset of discussing doing business together.

Module on intellectual property

1.3.6 Patent searching

Speaker: Aoife Tierney from Trinity College Dublin
Objective: To train ESRs into checking if anyone has done something similar in term of patents, trademarks, publications or marketing googling via a Wi-Fi interactive session where ESRs use their own mobile devices.
Description: No pattern can be enforced until it is granted. Sometimes, the patent has expired or ceased. A patent gives you right to stop anybody from using it for 20 years. After 20 years, it is of public domain. A basic pattern is defined by numbers. Useful online resources are EPO (European Patent Office), USPTO, PCT, Irish Patent Office, Searching biological sequences and more. Focus is placed in searching patents using Espacenet. Espacenet is a patent database hosted by EPO with advanced search options including full text, keywords and symbols search.

If more general words are employed in the search, a broader field will be covered. With patent searching, you want to limit the number of results to have a focused research. Therefore, it is advisable to:

- Pick appropriate keywords

- Use classification codes if possible
- Give yourself some time. There is no quick solution.
- Save applicable patents in "my patents" list for future reference
- Can print out front covers to see if patent is applicable

Databases for trademarks: Irish Patents Office, UK Intellectual Property Office, European Union Intellectual Property Office (EUIPO), International Trademark Association (INTA). Databases for designs: UK Intellectual Property Office, European Union Intellectual Property Office (EUIPO), World Intellectual Property Offices (WIPO). A practical demonstration is carried out using the eSearch plus tool in EUIPO.

Module on patent searching

1.3.7 Creating organizational structures

Speaker: Denis Kelly from ESB
Objective: To help ESRs achieving success with vision, culture (how to convince Universities, regulators, etc.), engage and design (thinking ahead) of organisational structure.
Description: The early stage implementation stages include identify, invent and implement. The latter evolves into being able to picture your product, development plan, development strategy, IP, etc… A video about a company that made it all work is presented to the ESRs. The video shows that when they put students into a clinical setting, they were stopped from coming with solutions, but identifying a problem. Rather than a solution to a conceptual or unknown problem, they were looking to identify the problem for which to look for a recognised solution.

What are the best problems? -> This is what vision explains. What are you designing – why? What's the need? Who is the customer? What is your vision for the idea? (i.e., picture yourself 4 years from now) Who is bought into that vision? Who do you need to convince that needs to spend money into something? What will keep you going when things get tough? It is very powerful to communicate your idea in 1 or 2 minutes pitch exercise. ESRs are asked to pick somebody in the room that are not normally with and to share some of their vision.

Culture is how your organisation works, it is the people piece: Personality (types and preferences), teams (forming, storming, norming, performing), silos and specialists, BIAS and perceptions (eyes of the beholder). Culture reflection: What is the culture like? How is it sustained? How can new people fit in there? What was the most important message for you?

Who to engage depends on your needs, product, market, stage of development, urgency, timing, their needs and WIFFT. How to engage covers identify and understand your stakeholders, have a clear vision and clear message for each, develop your engagement plan, understand your markets, meet potential customers, investors, etc., raise awareness -become visible-, build networks, etc.

Organization design is: (a) a process for improving the probability that an organization will be successful, (b) the link between the goals of the organization and how managers and staff work to achieve those objectives, (c) assessing and re-shaping the organisation's structure and positions to better meet goals, and (d) determining the optimal organizational design after assessing strategy and plans, stakeholders, customers, culture, core and supporting processes and systems, critical tasks.

Module on creating organizational structures

1.3.8 Commercialisation and exploitation

Speaker: Caroline Gill from University College Dublin
Objective: To help ESRs identifying if there is a commercialisation application for the work they are doing. To provide an overview of the commercialisation and exploitation process (market assessment, types of IP and how to manage them, money, the team, the plan).
Description: The session is divided in two parts. While the first part is focused on the theory, the second part is a practical exercise where ESRs work in teams to do a commercialisation canvas taking the template at UCD Commercialisation and Exploitation division at Nova as reference. At the start of the class, a short video with a history of successful entrepreneurs is presented to the ESRs. It is explained how to license the technology from University to manufacturer. Recommendations are given to keep a commercialisation notebook to keep record of ideas, people that you talk to, etc. Innovation occurs at an intersection of technology, business and people. The commercialisation process develops as follows: (i) Why technology is better than existing solution, (ii) invention disclosure form, (iii) commercial potential (the market to place the product), (iv) protection strategy, (v) commercial strategy, (vi) license or spin-out.

When applying for commercialisation funding, it is typically best to go for a narrow segment of the market. When coming out with a commercialisation plan, it is necessary to be become familiar with regulations that influence how the sector works. Also to check that there is an opportunity in the market. Information on the market can be found in University library and state agencies, patent websites, academic papers and trade publications, academic and industry conferences (check competing products), … In the case of TRUSS, two ESRs already have patents of their own. It must be noted that while in University, inventors will be rewarded from IP, in

companies, companies take the reward from IP. A distinction between assigning a patent and licensing a patent is established. If you assign a patent to a company, if company fails, you lose the patent to pay debts. If you license a patent and the company fails, the University recovers the patent. Patents are a form of IP that is easier to protect, legal right with a concrete way of enforcement (protection for 20 years). Other forms of IP are revised: copyright (protecting expression of ideas as opposed to ideas, i.e., software development), know how, trademarks, design rights. Patents must be novel, not obvious to experts and capable of industrial application. Care must be placed upon avoiding disclosing a potential patent in a conference given that once it becomes public domain, it will not become a patent (i.e., novelty is destroyed). You have to decide about filing a patent at the beginning, before it is published anywhere. Once patent is granted, it gives you the right to exploit it within a geographical region. I have to decide which countries where to file a patent.

There are two routes to commercialisation: (a) create a start-up company, (b) license the technology to a existing company (my technology enhancing one of the company products). Sources of funding include sales money (i.e., provide services for customers. When raising money, there is no money like sales money, but it takes time), friends and family, state or international funding (SFI, Enterprise Ireland), angel investors and venture capital. The latter will want a percentage of your company.

In the 2nd half of the session, ESRs were divided in three groups that used post-it notes to fill the nine building blocks (problem, solution, value proposition, key resources, customers, key roadmap activities, commercialisation route, funding requirements and plan, and competitors) of a commercialisation canvas that will be the basis for the commercialisation plan. The first part of the process is brainstorming, when ideas are placed even if they are not validated yet. The teams were organised to be as multidisciplinary as possible to exploit diversity. A commercialisation plan is then formulated from the practical tool given by the canvas. In the canvas, you pick on problem to work on, come up with as many customers as you can, group the customers into segments. If you struggle to come up with customers, then, it is not a good idea and it is best to choose other problem. Summarizing, 1- Look at the market, who will pay for it? 2 – Decide how to manage your IP, 3 – Think about your team, 3 – Best solution is at intersection of business, technology and people, 5 – Use the commercialisation canvas with your team to brainstorm, and to quickly validate ideas and make a plan.

Module on commercialisation and exploitation

PROJECT MANAGEMENT COURSE

1.3.9 Introduction to project management

Speaker: Andrew Gibson from DCM Learning
Objective: This one-day bespoke project management course provides ESRs with all the essential skills, tools and techniques that they need to successfully lead or support projects.
Description: The course concentrates on the practical techniques that can be applied directly to each ESRs' workplace or project environment. The course focuses on the fundamental principles of successful project management and incorporates a number of easy to apply, effective tools and techniques that will give ESRs a common language and baseline of understanding of how projects should be managed internally. The training is highly interactive and includes facilitated discussions, group workshop activities and case studies.

By the end of the course each ESR will: (i) Recognise when it is appropriate to adopt a 'project' approach to managing workload; (ii) Clearly define projects to provide clarity in terms of scope, roles and responsibilities and other key factors; (iii) Apply a simple lifecycle to a project to break it into easy to manage stages; (iv) Be more effective in monitoring and controlling the project work, change requests and resourcing pressures by using best practice processes and techniques, and (v) Understand what lessons can be learned from managing work using a project approach.

Project Management is a temporary endeavour with a beginning and end to create a unique product, service, or result. Each project consists of 5 stages of initiating, planning, executing, monitoring and controlling, and closing.

The first step for initiating the project is people engagement in order to acquire information and knowledge. This group of people should be engaged in the process of the project and can be all the stakeholders that are involved in. Who is the stakeholder? Persons or organisations (customers, sponsors, performing organisation or the public) who are actively involved in the project or whose interest may be positively or negatively affected by the performance or completion of the project". Two types of stakeholders could be involved in each project:

- Internal stakeholder actively works in the project
- External stakeholder not actively works in the project.

The PM acts as a link between internal and external stakeholders. Also, PM is responsible to generate a map plan about the entire stakeholders and to make a decision to highlight the importance of total effect of each during a specific period of time. Another key factor for being a successful PM is the importance of knowing Business People Language to extract and translate it for planning the project. All the topics covered on the training programme are listed in the following course outline:

- Topic 1: An Introduction to Project Management
  - Defining what we mean by a project
  - The project lifecycle
  - The role of the Project Manager and other key stakeholders
- Topic 2: Project Planning
  - Defining a project – setting and agreeing objectives, scope and constraints

- Useful tools and techniques used in planning a project including work breakdown structures, Gantt charts, network diagrams and critical path analysis;
- Simple risk management tools and techniques

- Topic 3: Project Implementation
  - How to monitor, track and control activities
  - Determining corrective actions to keep the project on track
  - Change management process and version control
- Topic 4: Closing and Reviewing Projects
  - Understanding the need for a controlled close to a project
  - Learning lessons – both positive and negative

Course on introduction to project management

COMMUNICATION/TRANSFERABLE SKILLS MODULES

This section builds upon communication/transferable modules from prior training that covered "Planning your research", "Presentation skills" and "Innovation workshop: Case Study" in the 1st training week and "Knowledge management: the path to innovation" and "Responsible conduct in research and innovation" in the 2nd training week.

1.3.10 Working with industry on collaborative research projects

Speaker: Audrey Crosbie from Trinity College Dublin
Objective: This one-day bespoke project management course provides ESRs with all the essential skills, tools and techniques that they need to successfully lead or support projects.
Description: Engaging for Industry allows: (a) access to world class research capability focusing on your challenges – near-term, medium and long, (b) access to highly trained engineers and scientists without long term commitments, (c) state of the art infrastructure – value for money approach to validate how infrastructure can support your business, (c) up to 6 years of Leveraged research funding – helps to de-risk projects by sharing the costs and allow future planning, (d) dedicated research funding – Horizon 2020 inclusion, (e) environment to network with other companies, (f) graduate Employment/Talent – evaluate future employees, and (g) access to intellectual property – strengthen your IP position.

The roadmap for Industry partnership in TCD follows the path: (i) Identify the key business and research challenges facing your organisation; (ii) Determine the key scientific challenges and capabilities required to provide solutions; (iii) Map these problems onto the competencies of the researchers; (iv) Meeting between researchers in company and University; (v) Identify outline programme – scope, scale and cost; (vi) Identify key business issues – IP, staffing, infrastructure; (vii) Determine most suitable funding mechanisms; (viii) Implement the programme, and (ix) deliver results.

Funding mechanisms with Science Foundation Ireland (SFI) are presented. SFI is the statutory body in the Republic of Ireland with responsibility for funding oriented basic and applied research in the areas of science, technology, engineering and mathematics with a strategic focus. 100% Industry funded collaborative (or contract) research is a bi-lateral agreement between Industry partner and University, that it is strongly aligned to established Industry mechanism and IP agreement.

Module on working with industry on collaborative research project

1.3.11 Leadership and people management/managing change

Speaker: Ian Barret from Walls Construction
Objective: To understand what leadership means in a work setting, the differences between management and leadership, effective leadership and leadership competencies, what employee management is and how to achieve it, what company culture is and its impact.
Description: Leadership is a relationship through which one person influences the behaviour or actions of other people. Leadership differs from management. On the one hand, management produces order and consistency, it got to do with structure, responsibilities, processes and systems. There is a focus on performance and results. On the other hand, leadership produces change and movement, it sets direction, aligns people to a vision or objective, it motivates and inspires. Research has identified poor leadership as a major reason why people leave organisations. There are 7 reasons why people do not value their leaders: lack courage, political operator, self-centred, reputational damage, inconsistent behaviour, don't get their hands dirty or lack a generous purpose. Leadership traits: Energy, desire to lead, integrity, self-confidence, intelligence, technical knowledge, emotional intelligence, extrovert. Challenges that leaders face in 2018 are international focus (globalisation), visionary, managing diversity, understanding the use and influence of IT and the importance of social media. Golden rules using social media: Be transparent, be judicious, write what you know, be careful, it is a conversation (write that way), follow code of conduct, create some excitement.

What is employee engagement? Great place to work, job satisfaction, etc. But employer and employee views may differ. Engagement opportunities exist at companywide level (recruit right people, training, use of communications, use of social events, meetings) and at individual level (feedback, coaching and mentoring, giving recognition, pay and rewards, employee

involvement, one to one communication). Research shows that engagement decreases absence level and it also increase revenue. A model of employee engagement will have the characteristics of rational think (they understand how their job fits), emotional feel (they like the people and business they work with) and motivational act (additional effort to go beyond).

Company's culture attracts or repeals those most needed. Strong culture affects performances and influences employee behaviour. Characteristics of effective culture are vision (mission statement / purpose), values, practices, people, narrative, and place. In order to change company culture: focus on communications; hire inspirational managers; invest in your people (feedback is important); eliminate unnecessary bureaucracy; understand culture is negotiated. Remember that companies have personalities (work in companies that think like you do) and they will want to align their employees with how they do things. So think about a company you may wish to work for in the future, think about is vision, values and practises, its past, present and future and the people that work there. Then decide. With a good culture, you will enjoy it, and you will stay even if you get paid less.

Module on leadership and people management/managing change

1.3.12 Grant writing-a short guide to survival and success

Speaker: Prof. Walter Kolch from University College Dublin
Objective: To teach ESRs the basis for a successful grant proposal. A grant is a sales pitch where you sell yourself, your vision, your ideas and your track/record and/or preliminary results.
Description: This session emphasizes the sale aspect when preparing a grant proposal. A proposal requires passion, ambition, vision, credibility, …. It is important to consider your strong points when selling yourself, i.e., your skills will ensure a positive outcome, and to show that you can manage a project. You need to sell your vision. Then the ideas (worth funding) come, i.e., what you need to do. 20-30% should be supported by preliminary results. You should refer to these results throughout the proposal and present them in an appealing way (i.e., avoid dotted graphs). If you do not have preliminary results, you must demonstrate you have the skills and/or explain why you are changing fields if that was the case.

A good grant proposal got a lot to do with presentation, i.e., making things look good, simple and appealing, with a clear overall concept and clear line of concept that avoids the reviewer thinking to understand it. Be simple, a single idea or hypothesis works best as opposed to getting lost including many side-lines. Having a clear focus minimises risk. Do not just list what could be done, but select what needs to be done in order to address the research question. How can a clear concept be developed? Start with an hypothesis, and develop Work Packages (WPs). The big question is divided into smaller questions, i.e., the WPs. The purpose needs to be explained. What are the outcomes? New knowledge, new applications, new methods, etc. The wow factor (a cool idea, an unexpected outcome) gets the reviewer excited about the proposal. Common mistakes are: too many side-lines projects; aims and workplan do not correspond; failing to explain how the workplan addresses the aims; failing to explain how different parts fit together; trying to do too much and staying superficial; neglecting effects of sample sizes.

The structure of the proposal will contain sections on background/state of the art, aims/objectives (It is recommended to break a big question into 2-4 aims), workplan and justification of resources. Often, the first pages win or lose a proposal. Instead of a lot of text, use pictures (i.e., a scheme of the concept) as people tends to be quite visual. The workplan is what you do, how you do it, what results you expect, how these results will address the aims, how the different subprojects work together towards the main goal. What collaborators are doing must be described clearly. Guidelines on impact can be seen in the sponsor website. Oral feedback is usually richer than a letter.

Module on grant writing-a short guide to survival and success

1.3.13 Career planning for PhD students

Speaker: Leonie Phillips from University College Dublin
Objective: To help ESRs to know themselves, to explore opportunities and to decide what to do taking into account their values and what their doctoral research offers them (specialist skills, experience, etc.).
Description: ESRs carry out a first exercise on work values where they rank and share their priorities based on what is important to them right now (i.e., achievement, prestige, authority, personal growth, autonomy, social interaction, risk taking, economic reward, variety, intellectual challenge, social good, creativity, physical environment, job security, work/life balance, …).

Once you are ready to apply for a job, where do you find a job? There are advertised jobs and hidden jobs. Hidden jobs are not advertised yet and they are obtained applying speculatively, volunteering, via internships or networking. What's your plan? Where am I now? Where do I want to be? Which is my back-up plan? These questions can be addressed by a second exercise facilitated to the ESRs, where they must fill a career goals worksheet for three different periods: short-term refers to 1

year, mid-range to 3-5 years, and long-term to 10 years. For each period, the ESR needs to answer where they want to be (their draft goal), and other boxes including:

- Specific: What is the desired job?
- Measurable: How can you quantify progress and completion?
- Achievable: What training, certification and skills are needed? What experience is necessary? What resources are needed? Do you need help from other people?
- Relevant: Is the goal in alignment with your values and strengths?
- Time-bound: What is the deadline? Is the deadline realistic?
- Final goal

Tip: Search in social media (i.e., LinkedIn) the path of people that were where you are now.

Module on career planning for PhD students

1.3.14 How to succeed at interview

Speaker: Leonie Phillips from University College Dublin
Objective: To improve the performance of ESRs at interviews; to understand the different types of interviews; to know how to prepare for an interview; to understand how to make a good first good impression; to have gained insight into some of the common questions and; to have the opportunity to practice a typical interview question.
Description: The purpose of an interview is to check that you have the skills, that you know what the job involves and what is required from you and to assess your motivation. It is a two-way process and you should also make them questions (i.e., what projects will I be working on? Who am I going to be working with?). Ask sensible questions (i.e., career progression).

The employer needs to know: Can they do the job? Will they do the job? Will they fit in? When they ask to tell them about yourself, you should highlight your education, experience, strengths and career objectives. Prepare for questions on yourself such as: Why did you apply for this job? What your skills and abilities relative to the role? What are your key achievements? What are your career goals and ambitions? What sets you apart from other candidates? Other question can be "What's your greatest weakness?" Be selective when answering this, it should not hinder your ability to do the job. Prepare also for questions about the job: What do you know about this role? Why have you applied for this role in particular? ESRs are introduced to the STAR (Situation Task Action Results) technique to answer competency based questions.

You should pay attention to your body language and tone of voice. Do not go blind into an interview. It helps to know the background of the panel of interviewers (HR? Technical? …). Get concrete feedback -> you are entitled by law. ESRs are asked to work in pairs to tell about themselves. They take turns for playing the role of interviewer and interviewee. Each pair gives each other feedback on answers, body language, tone of voice, etc. The career centre of the University provides service such as mock interviews given a job specification and CV. A wealth of information can be found in the UCD Career Development website and others. In addition to lecture notes on "How to Succeed at Interview", ESRs are provided with notes on "How To Make An Effective Application – CV's and Cover Letters".

Module on how to succeed at interview

TEAM ACTIVITIES

A cultural visit to Book of Kells, library and museum in TCD and to Johnny Foxes, organised by Trinity College Dublin and University College Dublin, aimed to form powerful relationships supporting each other's professional growth.

1.3.15 Cultural visit to Book of Kells and Irish Folklore

Objective: To promote team cohesion and networking between all researchers, ESRs and supervisors, in an informal environment.
Description: ESRs were guided by TCD staff into a technical and historical tour of the buildings in campus on Monday and Tuesday afternoon. ESRs and supervisors had a dinner in Johnny Foxes on Thursday evening. This is one of Ireland's oldest venues for traditional Irish folklore.

Cultural visit to Book of Kells and Irish Folklore

RESEARCH SEMINARS

Objective: Research Seminars (presentations by fellows on their individual research projects) followed by face-to-face doctoral studies panel meetings took place on the Thursday 18th January. These seminars have also taken place in the two previous training weeks. They allow fellows to train their communication skills and to get feedback from the consortium

for their Research and Personal Career Development Plans (PCDPs).

Description: These seminars are interactive presentations by ESRs that prepare them to present their own work at other national and international events. Here, presentations are confined to TRUSS partners and researchers local to the host venue who wished to attend. In this 3rd training week, the theme of each presentation has been around the research progress and plans to complete their commitments with TRUSS and their PhD thesis timely. These research plans are described in detail in the PCDPs by all ESRs. After presentations, each ESR was called on an individual basis for face-to-face meetings with his/her DSP to discuss the PCDP.

Reliability of concrete structures reinforced with braided FRP by ESR1

Reduction of uncertainty in assessing concrete strength of existing structures by ESR2

Reduction of uncertainty in design of free standing nuclear spent fuel rack by ESR3

Probabilistic optimisation of the design of offshore wind turbine towers by ESR4

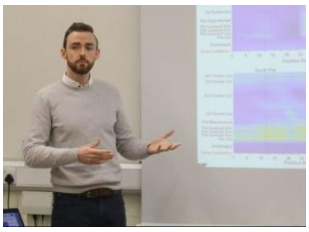
Integrity management of ship structures by ESR5

Residual life assessment and management of ship unloaders by ESR6

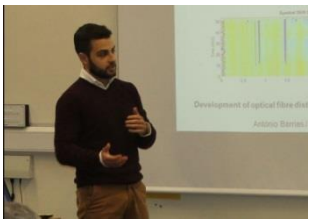
Railway Weigh-In-Motion for bridge safety by ESR7

Probabilistic modelling of bridge damage based on damage indicators by ESR8

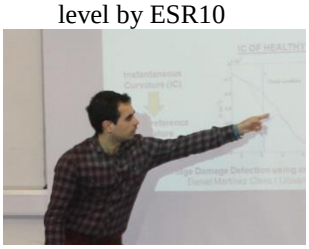
Railway bridge condition monitoring and fault diagnostics by ESR9



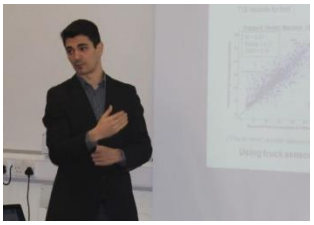
Assessment of bridge condition and safety based on measured vibration level by ESR10



Development of optical fibre distributed sensing for SHM of bridges and large scale structures by ESR11



Bridge damage detection using an instrumented vehicle by ESR12



Using truck sensors for road pavement performance investigation by ESR13

Reduction of uncertainty through regularized, automated road inspection by ESR14

Module on research seminars

Further information about the 3rd training week can be found on TRUSS website (http://trussitn.eu/?p=18873).

1.4 TRAINING WEEK 4

Training week 4 was a 4-day QQI6 project management course organized by TRUSS and designed by DCM learning to give ESRs a fast track introduction to the skills that are required to work effectively while managing projects of all sizes. This course, together with contents of the 3rd training week, addressed contributed to address a recommendation by the PO for further developing management skills. By submitting the final written assignment due in six weeks after the last training day, ESRs will receive the QQI Level 6 Certificate. The course was delivered from Andrew Gibson from DCM starting on the 11 June 2018 during 4 consecutive days from 9:30 to 5:00 pm at UCD School of Civil Engineering.

Andrew Gibson from DCM delivering the course

Eleven TRUSS ESRs (Sofia Antonopoulou (ESR1), Md Shah Nur Alam Sourav (ESR2), Alberto Gonzalez Merino (ESR3), Rui Teixeira (ESR4), Giulia Milana (ESR6), Farhad Huseynov (ESR7), Barbara Heitner (ESR8), Matteo Vagnoli (ESR9), Daniel Martinez Otero (ESR12), Federico Perrotta (ESR13), and Siyuan Chen (ESR14), TRUSS project manager and two researchers from outside TRUSS, Elena-Alexandra Micu (from NSF-SFI project on image processing to analyse traffic on bridges) and Emina Balic (from FP7 SUPRA ITN), attended the course.

Trainees

The ESRs were inducted into the project management concept by participating in group exercises to act as a project manager. The importance of factors such as time management, data collection and analysis, and team-work were discussed and the characteristics of the project manager were defined.

Sofia Antonopoulou at Project Management Course

Federico Perrotta at Project Management Course

Description: Project management is the application of knowledge, skill, tools, and techniques to project activities to meet project requirements. Project management is accomplished through the application and integration of 5 project management processes as listed below:

- Initiation: Initiation is the first phase of the project lifecycle. This is where the project's value and feasibility are measured.
- Planning: The project plan gives the team direction for producing quality outputs, handling risk, creating acceptance, communicating benefits to stakeholders and managing suppliers.
- Execution: is all about completing work defined in project management plan to satisfy the project specification through co-ordinating people and resources, and integrating and performing activities as set out in project management plan.
- Monitoring and controlling: Involves controlling changes and recommending preventative actions and influencing factors to circumvent integrated change control ensuring only approved changes are implemented.
- Closing: Teams close a project when they deliver the finished project to the customer, communicating completion to stakeholders and releasing resources to other projects. Project management isn't just about assigning and following up on tasks but also the skills a project manager must practice and master to manage a project efficiently.

The ten knowledge areas of project management are given in the subsections that follow.

1.4.1 Project stakeholder management

What is a stakeholder? "Persons or organisations (customers, sponsors, performing organisation or the public) who are actively involved in the project or whose interest may be positively or negatively affected by the performance or completion of the project" (PMBOK® Guide 5th Edition). Identification of all stakeholders is an important activity of the project manager to ensure project success.

- Methods to Analyse Stakeholders:
- Power & Interest Grid: This model classifies stakeholders based on their power and interest in the project. It allocates the stakeholders to one of the categories:
- Power and Influence Grid: this model is somehow similar to the first model and two attributes are assigned to the project stakeholders.
- Salience Model: A classification of stakeholders based on power to influence, the legitimacy of each stakeholder's relationship with the organisation, and the urgency of the stakeholder's claim on the organisation.

1.4.2 Integration management

Project Integration Management: Project Integration Management includes the processes and activities needed to identify, define, combine, unify and coordinate the various processes and activities within the project management process groups.

The following project planning and execution models are used for medium to large projects within organisations where

most of the team members are subordinate of the project manager.

Project Charter: Project Charter refers to a statement of objectives in a project. This statement also sets out detailed project goals, roles, and responsibilities identify the main stakeholders, and the level of authority of a project manager.

Business Case: The Business Case is a one-off, start-up document considered by senior management to assess the pros and cons of proposed projects (initiatives), or to assess the options for a project that has already had resources allocated. The Business Case presents the business issue, identifies project options, benefits, costs, risks and defines the scope. A project manager should answer two crucial questions before producing a business plan:

- Is the project aligning with company and market?
- Do we have the capabilities?

The business case will analyse the following economic models:

- Benefit Cost Ratio
- Payback Period
- Present Value
- Net present Value

Work Breakdown Structure: A work breakdown structure (WBS) is a key project deliverable that organises the team's work into manageable sections. The work breakdown structure visually defines the scope into manageable chunks that a project team can understand, as each level of the work breakdown structure provides further definition and detail.

1.4.3 Project Scope Management

The key stakeholders need to be constantly reminded of the agreed scope of the project and that any changes will only occur according to the agreed procedures. The Scope Statement or Goal, which was developed at the end of the Initiation Phase is very useful to help control scope creep.

1.4.4 Project Time Management

Time management is another key aspect of managing a project. As such, it is considered to be a core knowledge area, and is closely knit to scope and cost areas:
Techniques for Cost and Time Estimation:

- Expert Judgment
- Analogous Estimating Top Down
- Parametric Estimating
- 3 point Estimating
- Reserve Analysis

1.4.5 Project Cost Management

The Cost Management Plan is part of the general project plan, it sets out to answer how the PM will manage cost. The Cost Management plan should be done early in the planning process. Elements of Cost Management Plan include:

- Accuracy: Establish levels of rounding
- Units of measure: Currency, staff hours
- Links to the PM Plan: WBS, RBS, Control Accounts
- Control thresholds: Variance +/-, %
- How will we measure performance: Earned Value
- Reporting Structure: Format, Frequency, Stakeholders
- Descriptions of Process for: Estimating costs. Cost Budgets, Control Costs

Andrew Gibson from DCM

1.4.6 Project Quality Management

The quality of the outcomes of the project is linked to the processes introduced to ensure quality. What is Quality? Degree to which the project fulfils requirements! There are 4 types of quality project report as listed below:

- Proposal Document
- Project Plan
- Variance Requests
- Status Report

1.4.7 Project Communication Management

Statement Of Work (SOW): The state of work allows the project team to fully understand their need and communicate these needs to protective seller. This will allow the sellers to determine if they can provide the product or service. The SOW includes the following:

- Specifications – performance, functions, designs
- Quantities
- Quality levels
- Performance data
- Period of performance
- Work locations
- Other – e.g. Response specification, length, deadline

The project manager should also set a legal professional to write the right contract. Common contract types are as below:

- Fixed Price Contracts
- Cost Reimbursable Contracts
- Time & Material Contracts T&M

1.4.8 Project risk management

All projects are subject to uncertainty and therefore to risk. Risk should be identified and ranked in terms of impact and probability. Responses are to be developed for those risks incurring medium to high impact or probability. Project Managers responsibility is to identify as many risks as they can. There are strategies to manage the risk as outlined below:

- Avoidance – plan in such a way to avoid the risk altogether
- Mitigation – plan to reduce the risk
- Acceptance – simply accept the risk if there is no alternative or if it is very unlikely or of little impact
- Procurement – contract out the risk – however the contract still needs to be managed carefully
- Contingency Planning – determine alternative strategies if the risk is triggered

- Insurance – transfer the risk through insurance (also a risky strategy)

1.4.9 Project Procurement Management

The purpose of procurement management plan is to document purchasing decisions, specify purchasing approach, and identify vendors. Procurement management sequential steps are as following:

1. Plan
2. Conduct
3. Close
4. Administer

1.4.10 Project Human Resources Management

Human Resources management places focus upon project Team recruitment, organization and management until the end of a given project and includes the following steps:

- Develop Human Resource Plan
- Acquire Project Team
- Develop project Team
- Manage Project Team

RACI Chart**:** RACI stands for Responsible Accountable Consulted Informed and is a matrix of all the activities or decision making authorities undertaken in an organisation set against all the people or roles.

ESRs Attending Project Management Course at UCD

Further information about the 4th training week can be found on TRUSS website (http://trussitn.eu/?p=16915).

Chapter 2: Supervised training and research

2.1 SUPERVISION ARRANGEMENTS AND PERSONAL CAREER DEVELOPMENT PLANS

All ESRs had dedicated supervisors, i.e., a main supervisor (from the institution of the beneficiary where the candidate will be located primarily), and co-supervisors from the participant where the candidate spent secondments. These supervisors are listed below.

- ESR1: Ciaran McNally (academic), Greg Byrne (industrial), Nick Warrior (academic)
- ESR2: Salam Al-Sabah (industrial), Ciaran McNally (academic)
- ESR3: Luis Costas (industrial), Arturo González (academic), Thierry Yalamas (industrial)
- ESR4: Alan O'Connor (academic), James Nichols (industrial), Maria Nogal (academic), Thierry Yalamas (industrial)
- ESR5: Kian Banisoleiman (industrial), Arturo González (academic), Michael Havbro Faber (academic)
- ESR6: Kian Banisoleiman (industrial), Arturo González (academic), Thierry Yalamas (industrial)
- ESR7: James Brownjohn (industrial), Eugene OBrien (academic)
- ESR8: Thierry Yalamas (industrial), Eugene OBrien (academic)
- ESR9: Rasa Remenyte-Prescott (academic), Matthew Brough (industrial), John Andrews (academic)
- ESR10: Joan Ramon Casas (academic), Joan Peset (industrial)
- ESR11: Joan Ramon Casas (academic), Sergi Villalba (industrial)
- ESR12: Eugene OBrien (academic), Jørgen Krarup (industrial)
- ESR13: Tony Parry (academic), Mohammad Mesgarpour (industrial), Luis Neves (academic), Helen Viner (industrial)
- ESR14: Debra Laefer (academic), Salam Al-Sabah (industrial), Eleni Mangina (academic)

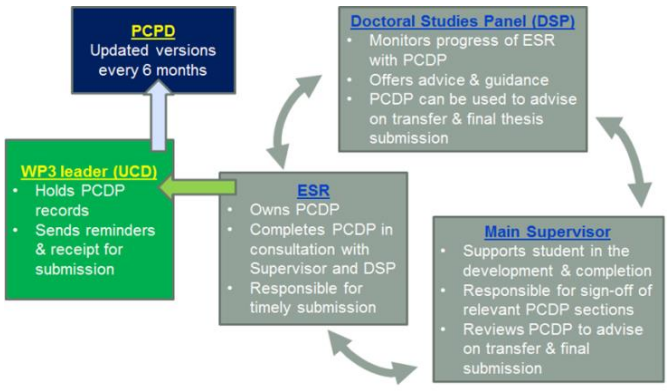
The supervisors above would be part of a DSP, also composed by the ESR and additional experts from a different participant who could influence the direction of research. The experts added to the DSP would typically be changed in each meeting to bring different perspectives into the project. This structure ensured that each DSP had representation from both industry and academia.

A total of 6 face-to-face DSP meetings took place following management meetings of the project, that were attended by principal investigators, supervisors and ESRs. In these DSP meetings, the ESR, the supervisor and other members of the DSP discussed the development and implementation of a PCDP to assess the progress of the ESR and advised on future research and training needs. The ESR submitted and circulated an updated PCDP to the DSP at least one week prior to each DSP meeting. In the management meeting preceding the DSP meeting, progress and technical issues in all WPs were reviewed via presentations by PC and all ESRs to the entire network that posed questions and suggestions to the speakers. Then, DSP discussions took place in separate focus groups (no fewer than four people) for each ESR. During these network-wide meetings, ERSs had an opportunity to practice their communication skills, to receive academic and/or industrial training, and to get feedback on their PCDPs.

The PCDP was divided into a number of sections:

- A brief overview of the research project and major accomplishments. In the first PCDP, the ESR provided a research plan and major accomplishments expected. In subsequent PCDPs, the ESRs provided an update of the progress in his/her research plan and major accomplishments achieved and expected.
- Long-term (5 years) goals. Here the ESR clarified goals and further research activity or other training needed to attain these goals. These goals were adjusted in further PCDPs as a result of the training received.
- Short-term (1-2 years) achieved and expected goals (including actions required) in research and research management:
  - Results: Publications, conference, workshop attendance, courses, and/or seminar presentations.
  - Skills and techniques: Training in specific new areas, or technical expertise, etc.
  - Management: Fellowship or other funding applications.
- Short-term (1-2 years) achieved and expected goals (including actions required) in:
  - Personal and professional excellence:
    - Communication and presentation, leadership and interpersonal skills, self-management and career development
    - Networking and collaboration opportunities, other activities with professional relevance (community, etc)
    - Other professional training: teaching activity, mentoring, course work, etc.
  - Innovation and transferable skills: Innovation process, IP management, business planning, commercialisation of research, policy development, etc.

The main supervisor, DSPs and PCDPs were key elements, as illustrated below, in the progression of the research towards a doctoral degree and the improvement of the employability conditions of the ESR.



Supervised research towards a doctoral degree

A Supervisory Board (SB) meeting took place immediately before each management meeting. SB were attended by one principal investigator (or institutional representative) for each beneficiary and partner, and one ESR representative, to discuss mainly budget issues, but also training needs. SB meetings served to bring up views and queries from ESRs via their representative, who engage with the management body to seek for areas of improvement. On Monday 30 November 2016, ESRs constituted their committee composed by Barbara Heitner, Rui Teixeira and Matteo Vagnoli, who represented the interests of ESRs at SB meetings following a rotational policy.

During the first three training weeks, SB and management meetings would take place on the Thursday, and the presentations by the ESRs to the network as part of the management meeting were labelled "Research Seminar" Module in Chapter 1. The following section reviews other network-wide meetings and training activities that took place outside the training weeks.

2.2 ANNUAL PLENARY MEETINGS

2.2.1 ENSA, Spain

The annual plenary meeting of TRUSS was hosted by ENSA in their premises of Maliaño (Cantabria, Spain), on 16 and 17 June 2016.

At ENSA, ERSs received different forms of training:

- Industrial Training consisting of a technical visit to ENSA. The General Manager, Rafael Triviño, and Nuclear Business Marketing & Sales Manager at ENSA, Guillermo Calleja, gave presentations on how the company has adapted to the changing conditions of the market from their foundation in 1973, the commercial strategy in the exploitation of their resources, internationalisation and product diversification, as well as safety rules prior to the visit. Then, TRUSS attendees were divided into three groups assigned to an expert (Javier Maldonado, Head of Engineering; Luis Costas, Senior Engineer and main supervisor in TRUSS; and Guillermo Calleja) that guided the TRUSS cohort through ENSA facilities. ESRs were able to observe the massive nuclear components under construction (there are single elements such as steam generators as heavy as 1000 tonnes with cranes able to lift up to 1300 tonnes). Alberto Gonzalez, ESR in project 3, showed the nuclear component in real scale, that he is working on (the free standing spent fuel storage rack), which is around 60 tonnes. ESRs received explanations on how these metallic structures are built, and they were able to eye-witness some of the processes of bore, weld, assemblage and transport employed in the manufacturing and delivery of these large structural components in a unique nuclear supplier facility.

Rafael Triviño, ENSA General Manager

ESRs, Supervisors and local researchers

Guillermo Calleja, Nuclear Business Marketing & Sales

ESRs prepared for the technical visit

Annual plenary meeting in ENSA

- Academic Training. The consortium had the privilege of the contribution of Prof. Enrique Castillo Ron from University of Cantabria, top elite researcher in the fields of extreme statistics, fatigue and Bayesian and functional networks, among others (https://www.researchgate.net/profile/Enrique_Castillo3). Prof. Castillo joined TRUSS for the day, when he delivered a master class on "Extreme Value Statistics" covering order statistics, limit distributions of order statistics, engineering examples, key recipes to deal with extremes and the mathematical background behind them. Prof. Castillo also participated in some DSP meetings and in the network activity, where ESRs and Supervisors benefited from his invaluable input.

Lecture by Prof Enrique Castillo

Prof Castillo from University of Cantabria

- Communication Skills. Each ESR presented the progress on their research and answered questions to the TRUSS consortium and local researchers from ENSA and University of Cantabria. These presentations were followed by separate meetings of each ESR with a small group of experts (DSPs) that provided feedback on the PCDP and research ideas. Discussions continued during network activities that took place after the DSPs.
- Networking Activity. ENSA organised activities that contributed to form professional relationships and to act upon research opportunities, share information and seek potential collaborators between ESRs, Supervisors and local researchers.


ESR1 Sofia Antonopoulou


ESR2 Shah Nur Sourav


ESR3 Alberto Gonzalez


ESR4 Rui Teixeira


ESR5 Guang Zou


ESR6 Giulia Milana

ESR7 Farhad Huseynov


ESR8 Barbara Heitner


ESR9 Matteo Vagnoli


ESR10 JJ Moughty


ESR11 Antonio Barrias

ESR12 Daniel Martinez


ESR14 Siyuan Chen

ESRs presenting in ENSA (16/06/2016)

2.2.2 *Arup, Ireland*

The MidTerm Review (MTR) meeting was held in Ove Arup and Partners Ireland, Dublin, on 1 and 2 December 2016. The MTR is a contractual obligation with the objective of meeting the project team, updating on the project progress, discussing any questions and finding improvements. It is therefore a unique opportunity to exchange views via a constructive dialogue between all network and the Research Executive Agency. The agenda started with a welcome by Arup Director, Joe Burns, followed by an introduction by Research Executive Agency representative, Nina Poumpalova, and external expert, Antonio Cimmino, and a Tour de table where all scientists-in-charge briefly presented their research team and described their role within the network. The round of presentations was initiated with the Coordinator's Report including scientific basis and progress of TRUSS ITN, training programme, networking and management.

Coordinator presenting


MTR participants

Afterwards, the ESRs presented their individual reports. Finally the REA representative met with ESRs and the meeting finished with an open discussion.


ESR1 Sofia Antonopoulou


ESR2 Shah Nur Sourav


ESR3 Alberto Gonzalez


ESR4 Rui Teixeira


ESR5 Guang Zou


ESR6 Giulia Milana


ESR7 Farhad Huseynov


ESR8 Barbara Heitner


ESR9 Matteo Vagnoli


ESR10 JJ Moughty


ESR11 Antonio Barrias


ESR12 Daniel Martinez


ESR13 Federico Perrotta


ESR14 Siyuan Chen

ESRs presenting in Arup (01 and 02/12/2016)

2.2.3 Lloyd's Register, UK

The 2nd annual plenary meeting of TRUSS was hosted by Lloyd's Register in their premises of 71 Fenchurch St. (London, UK), on 24 and 25 May 2017. The agenda included the delivery of 1st TRUSS Workshop and Supervisory and Management Board meetings.

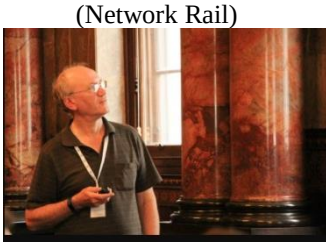
- TRUSS Workshop on the 24th May. In order to attract a local audience, the workshop addressed challenges raised by London Infrastructure Plan 2050, i.e., how to maintain buildings, energy and transport infrastructure that constitute the basic pillars for providing social and economic benefits to a growing London. The conclusions of the workshop can be easily extended to the context of other European cities. The workshop was organized through interaction with local professional organizations (i.e., Lloyd's Register Trust Fund, Network Rail, John Dora Consulting, and Imperial College London). Guest speakers from outside the consortium were also invited to give talks. The workshop featured talks by a panel of 6 renowned experts, discussions and a poster exhibition showcasing 14 related projects by TRUSS Early Stage Researchers. The targeted audience were policy makers, owners, operators, managers, research scientists, engineers and practitioners interested in life cycle maintenance, risk and probabilistic analysis of engineering structures and structural health monitoring. Direct invitations by email and flyers were posted to people with profiles fitting the themes of the workshop. Additionally, an extensive social media campaign with ads using YouTube videos, Twitter, Facebook, LinkedIn, and Google+ were employed to promote the event. The event was free, but registration was essential due to limited seats available, which was managed via Eventbrite.

Together with the 14 Early Stage Researchers and their individual TRUSS projects, the following experiences in structural safety, probabilistic analysis and health monitoring by worldwide experts were presented:

- "Bridge Management Asset at Network Rail" by Robert Dean (Network Rail)
- "Thoughts about the Risks in Adopting Risk-Based Strategies" by John Dora (John Dora Consulting Ltd)
- "Resilient Infrastructure: the Role of Structural Health Monitoring" by Prof James Brownjohn (Full Scale Dynamics Ltd)
- "Probabilistic Assessment of Bridges – Case Study Presentation" by Assoc. Prof Alan O'Connor (Trinity College Dublin)
- "Decision Theoretical Framework to Offshore Structural Integrity Management" by Prof Michael Havbro Faber (Aalborg University)
- "Methods and Tools for Reliability Assessment" by Dr Thierry Yalamas (Phimeca Engineering)


Robert Dean
(Network Rail)


John Dora
(John Dora Consulting Ltd)


James Brownjohn
(Full Scale Dynamics Ltd)


Alan O'Connor
(Trinity College Dublin)


Michael Havbro Faber
(Aalborg University)


Thierry Yalamas
(Phimeca Engineering)

TRUSS Workshop on the 24 May 2017

There were a total of 43 attendees, including independent consultants, and non-academic institutions such as Arup, Equipos Nucleares SA, Full Scale Dynamics Ltd, John Dora Consulting, Lloyd's Register, Microlise Ltd, MPW R&R Ltd, Network Rail, Phimeca Engineering, Rolls Royce, Transportation Research Laboratory and WPA Design & Build Ltd. Academic researchers from Aalborg University, Cranfield University, Imperial College London, King's College London, Trinity College Dublin, University College Dublin, University College London, Universitat Politecnica Catalunya and

University of Nottingham also attended the event. During the workshop, ESRs had the opportunity to improve their knowledge and expand their horizons further, and also to practise their networking and communication skills via a poster presentation to interested stakeholders. Discussions continued during the network dinner that took place after the workshop.

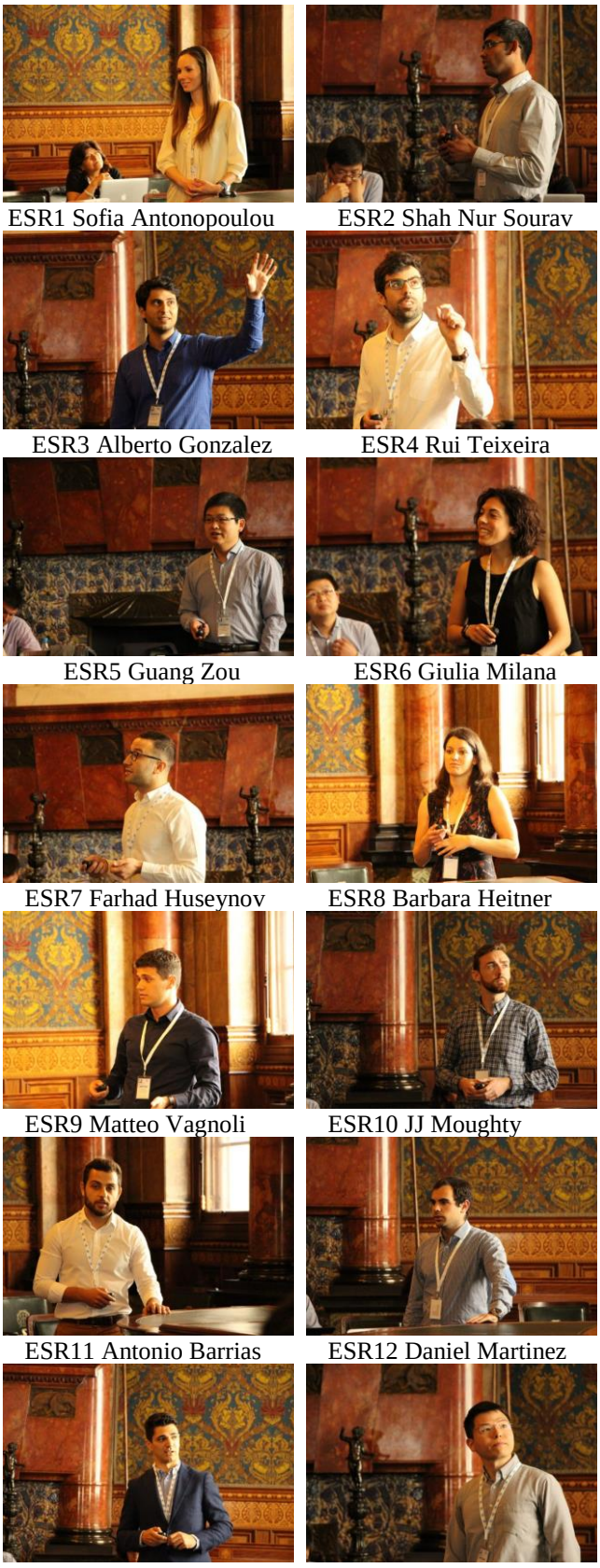
Poster exhibition by ESRs

Supervisory Board and Management meetings on the 25th May. The project coordinator (Arturo Gonzalez) first reviewed financial matters and other items with the members of the Supervisory Board composed by Salam-Alsabah from Arup, Luis Costas from ENSA, Kian Banisoleiman and Wendy Mann from LIoyd's Register, Thierry Yalamas from Phimeca Engineering, Gordon Airey and Luis Neves from UNOTT, Joan Ramon Casas from UPC, Eugene O'Brien, Debra Laefer and Loreto Manriquez from UCD, And Matteo Vagnoli as ESR representative. Further on, all ESRs joined the meeting to follow progress in all Work Packages and to report on their own research.

PC reporting on outreach activities | Rui reporting on research progress

Supervisory board and management meetings

- Communication Skills. Each ESR presented the progress on their research and answer questions to the TRUSS consortium and local researchers from UK. These presentations were followed by separate meetings of each ESR with a small group of experts (DSPs) that provided feedback on the personal career development plan (PCDP) and research ideas.



ESR1 Sofia Antonopoulou | ESR2 Shah Nur Sourav

ESR3 Alberto Gonzalez | ESR4 Rui Teixeira

ESR5 Guang Zou | ESR6 Giulia Milana

ESR7 Farhad Huseynov | ESR8 Barbara Heitner

ESR9 Matteo Vagnoli | ESR10 JJ Moughty

ESR11 Antonio Barrias | ESR12 Daniel Martinez

ESR13 Federico Perrotta | ESR14 Siyuan Chen

ESRs presenting in Lloyd's Register (25/05/2017)

2.2.4 UCD, Ireland

The 3rd annual plenary meeting of TRUSS was hosted by UCD on 28 and 29 August 2018. The agenda included the

delivery of 2nd TRUSS Workshop in UCD Sutherland School of Law during the 29th and the Supervisory and Management Board meetings held in UCD School of Civil Engineering on the afternoon of the 28th. This was the 8th network-wide meeting following others in UCD (February 2015 and January 2018), UNOTT (December 2015), ENSA (June 2016), Arup (midterm review in December 2016), UPC (January 2017), and LIoyd's Register (May 2017). The agenda consisted of:

- Supervisory Board (3:30 pm). The project coordinator (Arturo Gonzalez) reviewed financial matters and other items with the members of the Supervisory Board composed by Salam Al-Sabah from Arup, Luis Costas from ENSA, Wendy Mann from LIoyd's Register, Alan O'Connor from TCD, Eugene O'Brien , Ciaran McNally, and Parisa Beizaei from UCD, Joanna Buckingham from AECOM, and Rui Teixeira as ESR representative.


Project Coordinator at Supervisory meeting

- Management meeting (4:00 pm). All ESRs, pictured below, joined the meeting to report on their individual contributions to the state of the art of their research as well as their training and communications activities throughout the entire project. These contributions and activities are summarized in the profile page of each ESR with TRUSS (See http://trussitn.eu/?p=12258)


ESR1 Sofia Antonopoulou ESR2 Shah Nur Sourav


ESR3 Alberto Gonzalez ESR4 Rui Teixeira


ESR5 Guang Zou ESR6 Giulia Milana


ESR7 Farhad Huseynov ESR8 Barbara Heitner


ESR9 Matteo Vagnoli ESR10 JJ Moughty


ESR11 Antonio Barrias ESR12 Daniel Martinez


ESR13 Federico Perrotta ESR14 Siyuan Chen

ESRs presenting in UCD (28/08/2018)

- Final presentation by coordinator (5:45 pm). The project coordinator gave total figures in dissemination, outreach and training activities achieved by the network as a whole. TRUSS also acknowledged and congratulated those ESRs that outstood in specific aspects of the communication of the project for their high level of participation and success in reaching the scientific and general public. (See http://trussitn.eu/?p=20339).

2.3 MEETING REQUIREMENTS FOR A DOCTORAL DEGREE

All TRUSS ESRs were enrolled in a PhD programme at one of the academic beneficiaries from their arrival to the project. Therefore, in addition to the research, training and dissemination activities related to TRUSS, ESRs had to meet a number of internal requirements by each University before they could submit their PhD thesis for assessment.

Each University establishes processes and procedures to monitor the progress of individual PhD students registered in a School. In particular, UCD assesses each student formally at the end of Stage 1 doctoral studies. Therefore, there is an internal University panel that assesses the progress of the student and their competence and capacity to complete a doctorate at the end of Stage 1 and at any other point in the programme. The assessment panel bases its judgement on a written statement of progress and a research plan from the candidate, and a written progress report from the Principal

Supervisor. The Panel also requires a presentation from the student and may interview the student and/or the Principal Supervisor. The photos below illustrate the time of the transfer presentation for some TRUSS ESRs, which took place throughout 2017.

Farhad Huseynov at PhD transfer (7/02/2017)

Daniel Martinez at PhD transfer (16/05/2017)

Sofia Antonopoulou at PhD transfer (14/06/2017)

Giulia Milana at PhD transfer (15/06/2017)

Guang Zou at PhD transfer (27/10/2017)

Regulations stablish that the PhD degree will be awarded on successful completion of a structured programme of research, study and personal and professional development. The core of the doctorate is a coherent programme of research, which requires that the student successfully completes original doctoral research, the outcome of which makes an original and substantial contribution to knowledge. The PhD degree shall only be awarded where the work conducted has been assessed on the basis of a submitted thesis in acceptable form and deemed to be of a satisfactory standard. The structured PhD normally also includes additional educational and training elements which develop the advanced knowledge, skills and competencies required for successful original research and/or support the acquisition of generic or transferable skills. A minimum number of taught credits is required to be achieved. Some the training activities provided by TRUSS ITN, typically together with additional evidence of having met the learning outcomes (i.e., reports, presentations), were acknowledged in the form of credits. In UCD, this was the case of modules CVEN40250 (Specialist Studies - 5 credits), CVEN40350 (Research Methods - 5 credits) and CVEN50000 (Industrial Experience - 10 credits), which rewarded one training week in TRUSS, a series of formal presentations with interactive questions & answers to/by local researchers, and Industrial placements in TRUSS respectively.

To date, two ESRs, Antonio Barrias and Guang Zou, have successfully defended their doctoral thesis in a VIVA. Other eight ESRs have submitted their thesis for examination and are waiting for their VIVA to take place, and the remaining ESRs are working on finalizing the thesis.

On 5 November 2018, Antonio Barrias (ESR11) became the first TRUSS ESR in defending his doctoral thesis in front of a jury appointed by the Doctoral Committee of the Technical University of Catalonia (UPC). The thesis, titled “Development of optical fibre distributed sensing for the structural health monitoring of bridges and large scale structures”, was directed by Prof. Dr. Joan Ramon Casas from UPC and Dr. Sergi Villalba from COTCA. The public defense was held in front of a jury composed by Angel Carlos Aparicio Bengoechea (President, UPC), Arturo Gonzalez (Secretary, University College Dublin, Ireland) and Michel Ghosn (Member, City University of New York, USA). Antonio presented the research carried out, the methodology used, the thesis content and specially the original contributions stemming from the research, and the conclusions and research to be carried out in the future, to an audience of near 20 people including supervisors, jury, researchers, academic staff and Antonio’s relatives and friends. Following a round of questions and deliberation, the panel and Doctoral Studies Committee decided to award Antonio with a cum laude distinction due to the significant advance in the state of knowledge, accredited by publications in indexed journals of proven relevance in the field and dissemination of results at leading conferences in the field.

Antonio presenting at his VIVA

On 23 January 2019, Guang Zou (ESR5) became the second TRUSS ESR in successfully defending his doctoral thesis in front of an examination panel appointed by the Postgraduate Committee at University College Dublin (UCD). The thesis, titled "Probabilistic Methods for Life Cycle Management of Steel Structures under Fatigue", was directed by Dr. Kian Banisoleiman from Lloyd's Register EMEA, Associate Prof. Arturo Gonzalez from UCD and Prof. Michael Habvro Faber from Aalborg University. The defense was held in Lloyd's Register Global Technology Centre (GTC) in Southampton in front of a jury composed by Prof. Torgeir Moan (External Examiner from the Department of Marine Technology in Norwegian University of Science and Technology), Dr. Daniel McCrum (Internal Examiner from UCD), and Dr. John O'Sullivan (Chair from UCD). The VIVA was also attended by Kian Banisoleiman and Arturo Gonzalez. Unlike the PhD VIVA in UPC, which was a public defence, the current VIVA took place under UCD regulations, where a VIVA is not opened to the public. Only the candidate, internal and external examiners and the chair are present. Supervisors can be present, but only as witnesses if authorized by the candidate. Guang's defense began with a 10-minute presentation focused on main contributions of thesis, after which, the Examiners posed questions to Guang on a chapter by chapter fashion, concluding at 1:00 pm when the Examiners considered that all aspects of the thesis have been examined to their satisfaction. Following a short period of deliberation, the Examiners awarded the doctoral degree subjected to minor corrections.

Guang Zou at his VIVA

Chapter 3: Secondments

This section provides details on training undertaken during secondments for each ESR. They are combination of long secondments in a different working and cultural environment under the supervision of a designated mentor (i.e., ESRs with an academic host will have a long secondment with an industrial beneficiary/partner, and viceversa) and other visits of short duration, i.e., to monitor progress with supervisors or to complete some training or experiment.

- ESR1: Sofia Antonopoulou, hosted by UCD, experienced secondments in two institutions: an Industrial partner in Ireland and an academic beneficiary in UK. In Burgmann Packings (18/01/2016 to 22/01/2016, 08/02/2016 to 12/02/2016, 25/07/2016 to 29/07/2016, 17/10/2016 to 21/10/2016, 05/12/2016 to 09/12/2016, 08/01/2018 to 23/02/2018), she carried out laboratory work, under the supervision of Greg Byrne, including: (a) Manufacturing braided BF preforms in different configuration and diameters, and (b) Resin impregnation tests. This experience gave ESR1 the experience in design and manufacture of braided composites necessary for the reliability assessment of their performance. Following characterisation tests and numerical analysis, design optimisation took place in UCD. In UNOTT (24/04/2017 to 28/04/2017, 08/05/2017 to 12/05/2017, 29/05/2017 to 02/06/2017, 05/03/2018 to 23/03/2018), ESR1 worked on simulations involving development of FEA models for braided BFRP composites using TexGen and Abaqus software, supervised by Prof. Nick Warrior.
- ESR2: Shah Nur Alam Sourav, hosted by Arup, needed to do laboratory works for the project which led to early start of his secondment in UCD (19/04/2016 to 19/10/2016) under the supervision of Ciaran McNally. ESR2 used the material and structural laboratory facilities in UCD to carry out analytical and experimental work on the new proposed testing methods and techniques.
- ESR3: Alberto Gonzalez Merino, hosted by ENSA, had secondments in two institutions: an academic beneficiary in Ireland and an industrial beneficiary in France. A main long period in UCD (30/01/2017 to 16/07/2017) supervised by Arturo Gonzalez was followed by a shorter period in Phimeca (9/01/2017 to 13/01/2017) assisted by Thierry Yalamas, and then short visits to UCD (24/08/2016 to 26/08/2016, 28/11/2016 to 01/12/2016). The justification is as follows. The reason for the main period is that the UCD modules that best meet the needs for his project took place in the 2nd semester starting in January 2017. These modules were “Simulation modelling” and “Multivariate analysis”. Moreover, the structure he was modelling was to be tested in a lab experiment taking place in Spain throughout Autumn 2016, when it was key for him to witness and follow the test, its implementation and collect data. As a result of networking within TRUSS, Phimeca provided a secondment opportunity (approx. 1 month) to strengthen the reliability part of his research from an Industrial perspective, and to apply the specialised software PhimecaSoft to his research. This took place in Autumn 2017, and it increased his exposure to different working environments. Other short stays in UCD (adding up to approx. 1 month in total) to receive academic support, feedback and training, took place as a result of extending his stay when participating in network-wide events in Ireland throughout the project.
- ESR4: Rui Teixeira, hosted by TCD, had secondments in two industrial beneficiaries: Lloyd’s Register (2 different offices) in UK and Phimeca in France. His secondment with Lloyd’s, under the supervision of James Nichols (principal engineer on wind loads), was divided in two periods of time. Placements in London (03/10/2016 to 09/12/2016) and Aberdeen (12/12/2016 to 10/02/2017) allowed him to develop competences in, a first phase, modelling offshore wind turbines and then in applying reliability methodologies in their analysis for developing robust designs that will minimize the risk to power supply interruption during the life of the installation. Additionally, this strategy presents as the main advantage the possibility of working with two Lloyd’s Register senior specialists in the topic. The second placement in Aberdeen was achieved by the previewed advantage of being able to settle the knowledge at TCD in mid-term between the secondment’s periods of time. Therefore, making an adequate balance between the time needed to consolidate work in the industry as it was considered that six months straight would limit the a more active collaboration between the two parties. The further change of final secondment period from Lloyd’s to Phimeca relates to the strong connection between the direction ESR’s research topic took and Phimeca’s expertise, particularly in the usage of Kriging surrogate models. As result of the ESR’s 4th PDCP panel it was concluded that it would be of the best interest to the ESR to finalize his secondment in France from 30/10/2017 to 01/12/2017 under the supervision of Thierry Yalamas, where he could significantly expand his knowledge on reliability using the mentioned type of models.
- ESR5: Guang Zou, hosted by Lloyd’s Register, had secondments in two institutions. First, he carried out probabilistic modelling of fatigue deterioration during the visit in UCD (28/09/2016 to 11/01/2017) in collaboration with his academic supervisor, Arturo Gonzalez. Second, he stayed in Aalborg university (18/04/2017 to 26/09/2017) with the motivation of developing a risk-informed structural integrity management method together with Prof. Michael H. Faber.
- ESR6: Giulia Milana, hosted by Lloyd’s Register, had her secondment divided into a main long period (6/02/2017 to 28/07/2017) in UCD supervised by Arturo Gonzalez and a number of shorter stays (15/10/2015 to 16/10/2015, 7/11/2016 to 17/11/2016) in UCD, and in Phimeca, supervised by Thierry Yalamas. The main stay took place from the beginning of February to the end of July when the ESR carried out a dynamic analysis based on

theoretical simulations of the moving load problem in a ship unloader as well as obtaining site-specific dynamic features from field measurements, that were then translated into fatigue calculations. Other short stays in UCD took place in the period (15-16/10/2016 and from 7/11/2016 to 17/11/2016) to receive academic support, feedback and training, and in Phimeca, Clermont-Ferrand, France, in the period 04/06/2018 to 14/06/2018 to gain knowledge about sensitivity analysis and the Phimeca software (i.e., PhimecaSoft) and bring new ideas back to Lloyd's Register.

- ESR7: Farhad Huseynov, hosted by Full Scale Dynamics Ltd., spent a 3 months secondment in UCD (03/04/2016 to 07/04/2016, 14/11/2016 to 03/03/2017) developing theoretical models for bridge damage detection under the supervision of Prof. Eugene OBrien. The ESR analysed the sensitivity of a new Bridge Weigh-In-Motion system based on rotations to a change in bridge condition, supported by the wide experience in the field at UCD.
- ESR8: Barbara Heitner, hosted by Phimeca, had a main long secondment period (30/10/2016 to 31/03/2017), and other shorter periods (15/10/2015 to 17/10/2015, 26/01/2016 to 29/01/2016, 03/05/2016 to 05/05/2016, 04/09/2017 to 06/09/2017) as it's very important for the ESR to meet regularly her academic supervisor, Prof. Eugene OBrien. She was based at a company where she gets all the support regarding reliability and probabilistic concepts but as a civil engineer and someone whose research focuses on bridges, the continuous support of and discussion with her academic supervisor was invaluable. At UCD, ESR8 carried out simulations and probabilistic calculations required by the project. UCD advised on how to relate the spatial distribution of bridge safety to measured damage indicators in bridges.
- ESR9: Matteo Vagnoli, hosted by University of Nottingham, spent his secondment in Aecom (former URS) supervised by Matthew Brough in the period 12/09/2016 to 16/12/2016. Aecom provided ESR9 with assistance in the modelling of railway infrastructure, for use in developing the state diagnostic methodology. The ESR gathered information about the monitoring of a railway tunnel by Aecom to propose an ensemble-based change-pint detection method for identifying unexpected behaviour.
- ESR10: John Moughty, hosted by Universitat Politecnica Catalunya, worked in COMSA offices in Barcelona, supervised by Joan Peset, in the period 03/10/2016 to 23/12/2016. ESR10 aided in some projects, primarily in the process of assisting research based design construction products into the general market. Proficient engineers with in-depth knowledge of equipment, signal conditioning, signal analysis and interpretation provided the ESR access to the whole process of design, testing and operation of a monitoring system on a real structure.
- ESR11: Antonio Barrias, hosted by Universitat Politecnica Catalunya, had his main part of the secondment in COTCA, supervised by Sergi Villalba, during the period 12/09/2016 to 10/03/2017. Nevertheless, further short visits were conducted through the use of the Optical Backscatter Reflectometry (OBR) acquisition system (property of COTCA) in laboratory experiments until December 2017. In the main period, he assisted COTCA in the monitoring procedure of a building and bridge in Barcelona where OBR based Distributed Optical Fiber Sensing (DOFS) were deployed to test the structure over extended gauge lengths. The secondment allowed the ESR to learn from COTCA's practical experience on SHM and instrumentation, and in particular, on the use of the Optical Distributed Sensor Interrogator technology based on swept-wavelength coherent interferometry to measure temperature and strain using optical fibre.
- ESR12: Daniel Martinez Otero, hosted by University College Dublin, had two short stays of 2 days in Greenwood Engineering premises in Denmark (29/09/15 to 01/10/2015, 10/04/2016 to 16/04/2016), supervised by Jørgen Krarup. Greenwood has equipment to measure pavement deflections and are well-established experts in pavement engineering. Via this secondment, the ESR met Greenwood staff and the vehicle subject of his project. The latter allowed the ESR to model a Traffic Speed Deflectometer (TSD) vehicle and to investigate how a bridge responds to a TSD, and relate this to bridge condition, deterioration and damages. A longer secondment period was performed between 27/10/2016 to 2/04/2017 to gather a deep understanding of what the traffic speed deflectometer exactly measures and if it is applicable to bridges the same way it does in pavements.
- ESR13: Federico Perrotta, hosted by UNOTT, experienced secondments in two institutions. A three months secondment (11/01/2016 to 15/01/2016, 19/09/2016 to 11/12/2016) was completed in Microlise, under the supervision of Mohammad Mesgarpour. This experience was useful to collect data, gain knowledge about truck fleet performance monitoring, data mining, and 'Big Data' analytics. In addition to training in truck sensor data collection, in particular with reference to fuel consumption and associated factors, such as dynamic axle loads and location referencing, he gained exposure to truck manufacturers and truck fleet operators and understand their priorities with respect to fleet fuel consumption and control. A two months and 2 weeks secondment (09/05/2016 to 13/05/2016, 23/01/2017 to 31/03/2017) was completed in TRL under the supervision of Helen Viner. This experience was useful to analyse data, gain knowledge about road conditions monitoring and road maintenance asset management, and for the interpretation of findings. ESR13 had training in road condition measurements of various factors including evenness, stiffness and geometry, and also exposure to highway authorities that helped him to understand their priorities in the area of road maintenance planning. Combining data in both secondments, the ESR built and delivered a database of condition measurements required for the research study.
- ESR14: Siyuan Chen, based in UCD, spent his secondment in Arup, under the supervision of Salam Al-Sabah, from 19/04/2016 to 31/7/2016 and from 01/09/2016 to 19/11/2016 to match the schedule with supervisors and Arup working arrangement. Arup

regularly becomes involved with the cycle of planning, design, maintenance and upgrading of Ireland’s infrastructure. This gave the ESR the opportunity to see how the developing technology could best be integrated into the existing life-cycle of infrastructure building. More specifically, he worked on a survey for 'Boland's Mills', an old building subject of investigation by Arup, using the drone technology of his project.

Chapter 4: Local training

Local training of ESRs encompasses a wide range of activities. Here, they are divided into (1) scientific/technical skills gathered theoretically via courses and practically via lab and field tests, (2) complementary/transferable skills, and (3) attendance/presentations in conferences, workshops, outreach activities and professional meetings beyond those with supervisors or doctoral studies panels.

4.1 SCIENTIFIC/TECHNICAL SKILLS

ESRs gathered technical training via attendance to theoretical seminars or courses related to their research projects. These technical courses are summarized in the bulleted list below:

- ESR1, Analysis of Composite Materials with ABAQUS, Dassault Systèmes Austria GmbH, Vienna, Austria, (24 hrs), 05/09/2016 to 07/09/2016.

ESR1 at ABAQUS course on composite analysis

- ESR1, Training on Scanning Electron Microscopy (SEM), Nano Imaging & Material Analysis Centre, UCD, Dublin, Ireland (2 hrs), 03/10/2016.
- ESR1, MATLAB Masterclasses - What's New in MATLAB, Solving Optimization Problems with MATLAB - UCD, Dublin, Ireland (4 hrs), 18/10/2017.
- ESR2, Familiarizing with the equipment in the laboratory, risk assessment, work safety, UCD, Dublin, Ireland (24 hrs), 30/03/2016 to 04/01/2016.
- ESR2, Concrete Technology Seminar, Arup, Dublin, Ireland (2 hrs), 11/11/2016.
- ESR2, Course Stress and finite element analysis, UCD, Dublin, Ireland (48 hrs), 12/09/2016 to 02/12/2016.
- ESR2, Course module on Fracture mechanics, UCD, Dublin (36 hrs), 25/09/2017 to 01/12/2017.
- ESR2, Course on PG diploma in Statistics, Trinity College Dublin, Ireland (autonomous learning), 06/11/2017 to 22/12/2017.
- ESR2, Introduction to Programming with Matlab (24 hrs), 11/06/2018 to 31/08/2018.
- ESR2, Course on "Contact and convergence in Abaqus-successful strategies" (8 hrs), 12/04/2018 to 10/05/2018.
- ESR3, Historical outline of welding techniques for pressure vessels. Comparison of existing methods, requirements, specifications and quality survey, ENSA, Santander, Spain (3 hrs), 23/10/2015.
- ESR3, Mechanical properties and characteristics of materials used in the nuclear industry for manufacturing of pressure vessels. ASME standards and certification. ENSA, Santander, Spain (3 hrs), 20/11/2015.
- ESR3, Overview of the current ASME III code and other existing international manufacturing codes. Introduction to manufacturing and quality control under ASME III code. ENSA, Santander, Spain (3 hrs), 27/11/2015.
- ESR3, Use of Helicoils inserts, ENSA, Santander, Spain (3 hrs), 24/04/2016.
- ESR3, Advanced statistical methods: The Monte Carlo Method, UCD, Dublin, Ireland (5 ECTS), 01/09/2016, Semester 1.
- ESR3, Multivariate Analysis, UCD, Dublin, Ireland (7.5 ECTS), 01/02/2017, Semester 2.
- ESR4, Course on Advanced Structural Analysis, TCD, Dublin, Ireland (44 hrs), 18/09/2015 to 18/12/2015.
- ESR4, Course on J1 – Wind Energy, TCD, Dublin, Ireland (30 hrs), 18/01/2016 to 03/05/2016.
- ESR4, Matlab code to analyse structures, 18/01/2016.
- ESR4, Lloyd's Register training on Offshore Wind Turbine modelling and certification (12 hrs), 05/12/2016 to 07/12/2016.
- ESR4, DNV Webinar about modelling corrosion, 25/01/2018.
- ESR4, DNV Learn how the latest software and cloud developments can support your offshore wind projects, 22/03/2018 .
- ESR5, Structural Reliability Theory, Imperial College London, UK, (27 hrs), 25/01/2016 to 21/03/2016.
- ESR5, Matlab Fundamentals, MathWorks Training Services, GTC, Lloyd's Register, Southampton, UK (7 hrs), 26/04/2016.
- ESR5, Fracture Mechanics module, UCD, Dublin, Ireland (36 hrs), 28/09/2016 to 11/01/2017.
- ESR5, Hugin Software - Decision Analysis with Bayesian Networks, Hugin Expert, Aalborg, Denmak, 24/04/2017 to 26/04/2017.
- ESR6, Structural Reliability Theory, Imperial College London, UK (27 hrs), 25/01/2016 to 21/03/2016.
- ESR6, Non-Destructive Examination, GTC, Lloyd's Register, Southampton, UK (35 hrs), 26/10/2015 to 30/10/2015.
- ESR6, Structural Reliability Theory, Imperial College London, UK (27 hrs), 25/01/2016 to 21/03/2016.
- ESR6, Matlab Fundamentals, MathWorks Training Services, GTC, Lloyd's Register, Southampton, UK (7 hrs), 26/04/2016.
- ESR7, Training on use of equipment in Mechanical Laboratory, University of Exeter, UK (16 hrs), 08/08/2016 to 09/08/2016.
- ESR7, Training on using Imetrum, University of Exeter, UK (16 hrs), 01/08/2016 to 02/08/2016.
- ESR7, Training on using spectrum analyzer, University of Exeter, UK (32 hrs), 01/08/2016 to 04/03/2016.

- ESR7, Structural Health Monitoring and Smart Sensing, Vibration Engineering Section, University of Exeter, UK (4 hrs), 04/07/2016.
- ESR7, Training on using accelerometers, FSDL, Exeter, UK (4 hrs), 14/03/2016.
- ESR7, Training on using strain transducers, FSDL, Exeter, UK (8 hrs), 07/03/2016.
- ESR7, Participant in 2017 Asia Pacific Europe Summer School (APESS) on Smart Structures Technology, Japan (120 hrs), 17/07/2017 to 04/08/2017.

ESR7 at APESS 2017

- ESR7, Trained by a PhD student at the University of Exeter to conduct a Forced Vibration Modal Testing, UK (4 hrs), 08/05/2018.
- ESR7, Attended summer school on Structural Vibrations and Testing at the University of Exeter, UK (45 hrs), 30/07/2018 to 03/08/2018.
- ESR8, Euromem: From uncertainties to partial safety factors calibration: Application to tensile membrane structures - Discover the birth of Eurocode, A training school of COST Action TU1303, University of Nantes, France (12 hrs), 29/09/2015 to 01/10/2015.
- ESR8, Introduction to random field modelling, Phimeca, France (2 hrs), 14/09/2016.
- ESR8, Lecture on 'Reliability assessment with adaptive surrogates based on SVM regression', Amphi Poincaré at Sigma Clermont, France (2 hrs), 19/05/2016.
- ESR8, Lecture on the 'Estimating rare event probabilities in finite random processes", Pôle commun ISIMA-Polytech Clermont, France (2 hrs), 28/04/2016.
- ESR8, Formation à l'utilisation de PhimecaSoft / Training of PhimecaSoft - Uncertainty propagation software, France (16 hrs), 11/12/2017 to 12/12/2017.
- ESR8, Introduction to Kriging, Phimeca, France (3 hrs), 06/03/2018.
- ESR9, Advanced methods for reliability, availability, maintenance, diagnostics and prognostics of industrial equipment, Politecnico di Milano (32 hrs), 16/11/2015 to 19/11/2015.
- ESR9, Centre for Risk and Reliability Engineering (CRRE) Seminar, UNOTT, Nottingham, UK (4 hrs), 07/12/2015.
- ESR9, Introduction to C++ for Engineering Programmers, UNOTT, Nottingham, UK (8 hrs), 11/02/2016.
- ESR9, Introduction to C++ for Engineering Programmers, UNOTT, Nottingham, UK (8 hrs), 18/02/2016.
- ESR9, Quantitative methods for Engineers, UNOTT, Nottingham, UK (16 hrs), 21/01/2016 to 28/01/2016.
- ESR9, Seminar titled “Infrastructure management research” at the Swiss Federal Institute of Technology, Switzerland (4 hrs), 17/03/2017.
- ESR9, Seminar titled” Risk Analysis of Power Plants”, at University of Nottingham, UK (2 hrs), 30/10/2017.
- ESR9, Seminar titled "Data centric Geoscience research and innovation", at the University of Nottingham, UK (2 hrs), 11/10/2017.
- ESR9, Participant in the 2017 Asia Pacific Europe Summer School (APESS) on Smart Structures Technology (120 hrs), 17/07/2017 to 04/08/2017.
- ESR9, Seminar titled "Object-oriented probabilistic safety analyses with AltaRica 3.0", held at the university of Nottingham (2 hrs), 06/10/2017.
- ESR10, Machine Learning Course, UPC, Barcelona, Spain (25 hrs), 17/02/2016 to 20/05/2016.
- ESR10, Structural Health Monitoring Using Statistical Pattern Recognition, Los Alamos Dynamics, Bilbao, Spain (20 hrs), 03/07/2016 to 05/07/2016.
- ESR10, Completed two online Matlab courses. One on Machine Learning and the other on Data Processing and Visualization (30 hrs), 15/11/2016 to 30/01/2017.
- ESR10, Participant in the 2017 Asia-Pacific-Euro Summer School on Smart Structures Technology (APESS 2017), Yokohama, Japan (120 hrs), 17/07/2017 to 04/08/2017.
- ESR11, Machine Learning Data, UPC, Barcelona, Spain (25 hrs), 01/03/2016 to 15/04/2016.
- ESR11, Optical Fiber Telecommunications, UPC, Barcelona, Spain (2 hrs), 15/12/2015.
- ESR11, "Corrosion detection in concrete bridges" presented by Prof. Al Ghorbanpoor from University of Wisconsin-Milwaulkee (1 hr), 05/04/2017.
- ESR11, Participant in 2017 Asia-Pacific-Euro Summer School on Smart Structures Technology (APESS) (120 hr), 17/07/2017 to 04/08/2017.
- ESR12, Simulation of hydraulic fracture networks in shale and Dislocation mechanism-based crystal plasticity at submicron scale (1 hr), 01/09/2017.
- ESR13, Introduction to Abaqus, UNOTT, Nottingham, UK (12 hrs), 06/11/2015 to 27/11/2015.
- ESR13, Quantitative methods for engineers, UNOTT, Nottingham, UK (12 hrs), 21/01/2016 to 28/01/2016.
- ESR13, Induction to the use of the UoN High Performance Computer (HPC) (4 hrs), 06/12/2017 to 07/12/2017.
- ESR14, UAV Licence Training, RPAS Training International, Weston Executive Airport Dublin, Ireland (14 hrs), 17/10/2015 to 18/10/2015.
- ESR14, Computational Imaging, Maynooth University, Maynooth, Ireland (7 hrs), 19/11/2015.
- ESR14, Visualising Environmental Data Using ArcGIS, UCD, Dublin, Ireland (2 hrs), 25/02/2016.

Also, practical technical training took place in the form of lab and field tests as follows:

- ESR1, Technical expertise in the design and manufacture of braided composite materials and manufacture methods, Burgmann Packings Ltd, Dublin, Ireland, Laboratory Test, 18/01/2016 to 29/07/2016.
- ESR2, Site visit, on site testing for assessment of existing structures, UCD, Dublin, Ireland, Field Test, 08/04/2016 to 28/06/2016.
- ESR2, Laboratory tests on the assessment of compressive strength of hardened concrete, Laboratory Test, 01/05/2016 to 19/10/2016.
- ESR2, Intermittent laboratory testing on screw pullout testing, Laboratory Test, 03/07/17 to 22/12/2017.
- ESR3, Intermittent attendance to physical model testing, Santander, Cantabria, Laboratory Test, 01/10/2016 to 01/01/2017.
- ESR7, Deflection measurements on arch type railway Viaduct, FSDL, Harrington, UK (8 hrs), Field Test, 03/08/2016 to 05/08/2016.
- ESR7, Dynamic Test on Mill on the Exe footbridge, FSDL, Exeter, UK (8 hrs), Field Test, 16/03/2016 to 17/03/2016.
- ESR7, Field Testing on Bascule Bridge, Vibration Engineering Section, The University of Exeter, UK (16 hrs), Field Test, 01/07/2016 to 04/07/2016.
- ESR7, Field Testing on Exe North Bridge, FSDL, Exeter, UK (8 hrs), Field Test, 16/03/2016 to 17/03/2016.
- ESR7, Vibration test and Genzyme Factory, FSDL, Waterford, Ireland (8 hrs), Field Test, 17/05/2016 to 18/05/2016.
- ESR7, Mill on the Exe footbridge dynamic measurements, (6 hrs), Field Test, 30/03/2016.
- ESR7, Testing Lab Bridge, FSDL,The University of Exeter, UK (60 hrs), Laboratory Test, 18/03/2016.
- ESR7, Peace bridge dynamic measurements, Londonderry, UK (6 hrs), Field Test, 30/10/2016.
- ESR7, Field Testing on Bascule Bridge, Exeter, UK (6 hrs), Field Test, 19/11/2016.
- ESR7, Mineral Line Bridge field testing, Somerset, UK (8 hrs), Field Test, 01/06/2017.
- ESR7, Williton Bridge field testing using opal accelerometers (8 hrs), Field Test, 27/06/2017.
- ESR7, Vibration testing of Queensferry Crossing cable stays (8 hrs), Field Test, 10/07/2017.
- ESR7, Williton Bridge modal testing (8 hrs), Field Test 13/07/2017.
- ESR7, Mineral Line Bridge field testing with Flying Scotsman (8 hrs), Field Test, 05/09/2017.
- ESR7, Bascule Bridge load testing, Exeter, UK (8 hrs), Field Test, 26/09/2017.
- ESR7, Experimental validation of novel axle detection system: Williton Bridge field testing (10 hrs), Field Test, 29/12/2017.
- ESR7, Collaborated with the research group at the Kyoto University and conducted experimental studies on a laboratory bridge structure (160 hrs), Laboratory Test, 22/01/2018 to 07/02/2018.
- ESR7, Vibration testing of a monopole structure (6 hrs), Field Test, 03/05/2018.
- ESR7, Attended operational modal vibration testing of a skyscraper in Canary Wharf (London), UK (10 hrs), Field Test, 26/06/2018.
- ESR7, Vibration testing of pile foundations. Blackpool, UK (10 hrs), Field Test, 30/06/2018.
- ESR7, Attended a vibration testing of a composite laminated timber floor structure (110 hrs) Field Test, 13/07/2018 to 24/07/2018.
- ESR7, Williton Bridge stiffening testing (30 hrs), Field Test, 20/08/2018 to 22/08/2018.
- ESR8, Visiting a bridge that has been subject of various measurements and continuous monitoring, Slovenia (2 hrs), Field test, 23/06/2017.
- ESR9, Visual inspection of a railway bridge with Network rail and AECOM (8 hrs), Field Test, 30/01/2017.
- ESR11, Work done as part of a short stay in the secondment at COTCA where a field test was being carried out in Sarajevo Bridge, Barcelona, Spain (14 hrs), Field Test, 19/01/2016 to 20/01/2016.
- ESR11, Work done as part of a short stay in the secondment at COTCA where a field test was being carried out in Sarajevo Bridge, Barcelona, Spain (28 hrs), Field Test, 22/02/2016 to 25/02/2016.
- ESR11, Aid provided in laboratory experiments, Structural Technology Laboratory, UPC, Barcelona, Spain (20 hrs), Laboratory Test, 11/10/2015 to 27/11/2015.
- ESR11, Execution of point load test on a small beam instrumented with DOFS, Structural Technology Laboratory, UPC, Barcelona, Spain (325 hrs), Laboratory Test, 01/04/2016 to 14/06/2016.
- ESR11, Laboratory test with four concrete beams instrumented with DOFS, Laboratory Test, 26/10/2017 to 11/12/2017.
- ESR14, Survey for 'Boland's Mills', ARUP, Dublin, Ireland (4 hrs), Field Test, 26/11/2015.
- ESR14, Aerial inspection Boyne viaduct bridge, UCD, Dublin, Ireland (4 hrs), Field Test, 06/07/2016.
- ESR14, Aerial survey - Christ Church Cathedral, Dublin, Ireland (4 hrs), Field Test, 11/07/2016.
- ESR14, Aerial survey - St Patrick's Cathedral, Dublin, Ireland (4 hrs), Field Test, 21/07/2016.
- ESR14, Wall - survey, Dublin, Ireland (6 hrs), Field Test, 13/08/2016.
- ESR14, Group survey - River Liffey, UCD, Dublin, Ireland (6 hrs), Field Test, 21/08/2016.
- ESR14, Image processing and 3D reconstruction for masonry wall, UCD, Dublin (20 hrs), Field Test, 20/10/2016 to 20/01/2017.
- ESR14, Ground survey of bridges in Wicklow, Ireland (8 hrs), Field Test, 22/04/2017.
- ESR14, Aerial survey of road-R759 in Wicklow, Ireland (8 hrs), Field Test, 25/04/2017.
- ESR14, Aerial survey of Boyne Bridge-2nd times, Ireland (8 hrs), Field Test, 09/05/2017.
- ESR14, Aerial survey of bridges in Wicklow, Ireland (8 hrs), Field Test, 10/05/2017.

4.2 COMPLEMENTARY/TRANSFERABLE SKILLS

A number of ESRs took language courses listed below to facilitate interactions within the consortium and to improve their career prospects.

- ESR1, German General Purposes 1 (LANG10100), UCD, Dublin, Ireland (24 hrs), 25/01/2016 to 27/04/2016.
- ESR3, English courses, Escuela Oficial de Idiomas, Santander, Spain (120 hrs), 01/10/2015 to 31/05/2016.
- ESR3, IELTS Test, Burgos, Spain (5 hrs), 12/12/2015.
- ESR3, English courses, Escuela Oficial de Idiomas, Santander, Spain (120 hrs), 01/10/2017 to 31/05/2018.
- ESR4, IELTS proficiency test: 7.5/9, UCD, Dublin, Ireland (3 hrs), 26/09/2015.
- ESR8, French course, Center FLEURA, Blaise Pascal University (50 hrs), 21/09/2015 to 06/01/2016.
- ESR9, French Level 1 new beginners evening classes, UNOTT, Nottingham, UK (36 hrs), 11/01/2016 to 09/05/2016.
- ESR10, Spanish language course, Merit School, UPC, Barcelona, Spain (50 hrs), 12/10/2015 to 15/12/2015.
- ESR10, Spanish language course, Don Quijote Language School, Barcelona, Spain (30 hrs), 20/11/2016 to 16/12/2016.
- ESR11, Catalan language course Basic 1, UPC, Barcelona, Spain (50 hrs), 13/09/2016 to 13/10/2016.
- ESR11, Catalan language course Basic 2, UPC, Barcelona, Spain (50 hrs), 03/11/2016 to 15/12/2016.
- ESR11, Catalan language course Basic 3, UPC, Barcelona, Spain (50 hrs), 19/01/2017 to 06/03/2017.
- ESR11, Catalan language course Elemental 1, UPC, Barcelona, Spain (75 hrs), 09/03/2017 to 01/06/2017.
- ESR13, French course Lev 1, UNOTT, Nottingham, UK (36 hrs), 15/10/2015 to 15/12/2015.
- ESR13, German course Lev 1, UNOTT, Nottingham, UK (36 hrs), 15/10/2015 to 15/12/2015.
- ESR13, German course Lev 2, UNOTT, Nottingham, UK (3 hrs), 17/10/2016 to 12/12/2016.
- ESR13, French course Lev 2, UNOTT, Nottingham, UK (3 hrs), 18/10/2016 to 13/12/2016.

Other complementary/transferable skills are listed below:

- ESR1, Building a successful academic career, UCD, Dublin, Ireland (2 hrs), 11/11/2015.

Building a successful academic career seminar

- ESR1, Lab Risk Assessment, Fieldwork Safety, Chemical Safety, UCD, Dublin, Ireland (4 hrs), 08/12/2015 to 15/12/2015.
- ESR1, EndNote X7 and EndNote Online, UCD, Dublin, Ireland (2 hrs), 28/01/2016, 17/02/2016.
- ESR1, Report writing for researchers, Tiernan Ivory, Irish Times Training, UCD, Dublin, Ireland (8 hrs), 29/11/2016
- ESR1, Career planning for researchers, UCD Nova, Dublin, Ireland (4 hrs), 20/07/2017.
- ESR1, Agile White Belt level Training - UCD Agile, Dublin, Ireland (4 hrs), 30/01/2018.
- ESR1, University teaching and learning practise seminar series - UCD Teaching & Learning, Dublin, Ireland (16 hrs), 01/05/2018 to 30/05/2018.
- ESR2, Research methods III (focused on written and verbal communication), UCD, Dublin, Ireland (1 semester), 25/01/16 to 29/04/16.
- ESR2, Endnote – reference management, UCD, Dublin, Ireland (1 hr), 01/02/2016.
- ESR2, Workshop on "PhD masterclass" (6 hrs), 26/02/2018 to 26/03/2018.
- ESR2, Analytical writing (2 hrs), 16/11/2017.
- ESR2, Analytical reading (2 hrs), 15/02/2018.
- ESR3, Traits of a Healthy Safety Culture: INPO, ENSA, Santander, Spain (3 hrs), 27/05/2016.
- ESR3, Lean Startup Methodology (21 hrs), 01/06/2016 to 01/10/2016.
- ESR3, Research and Professional Development Planning, UCD, Dublin, Ireland, 24/08/2016 to 26/08/2016.
- ESR3, Bibliometrics: using metrics in your CV Workshop (3 hrs), 10/03/2017.
- ESR3, Social Entrepreneurship module, UCD Innovation Academy, Dublin, Ireland (5 ECTS), 15/05/2017 to 19/05/2017.
- ESR5, Corporate online training: Introduction to H&S, Display Screen Equipment (DSE), DSE Workplace Assessment, Drug and Alcohol, STOP Rule, Fire Safety Awareness, Environmental Management Awareness, Ant-Bribery and Anti-Corruption, Asbestos Awareness, Hazard Awareness, GTC, Lloyd's Register, Southampton, UK (7 hrs), 14/09/2016.
- ESR5, Presentation on the Town hall meeting about marine consultancy, Lloyd's Register GTC, Southampton, UK, 23/11/2017.
- ESR6, Field Safety training, GTC, Lloyd's Register, Southampton, UK (7 hrs), 07/12/2015.
- ESR6, Course on training and presentation skills, GTC (LR), Southampton, UK (21 hrs), 24/10/2017 to 26/10/2017.
- ESR7, Academic writing for doctoral students (AW4 T2), University of Exeter, UK (14 hrs), 19/01/2016 to 01/03/2016.
- ESR7, Presentation skills, University of Exeter, UK (8 hrs), 18/02/2016 to 10/03/2016.
- ESR8, Introduction to Latex, Phimeca, France, (2 hrs), 07/06/2016.
- ESR9, Academic discussion skills, UNOTT, Nottingham, UK (4 hrs), 10/11/2015.
- ESR9, Getting on with your thesis, UNOTT, Nottingham, UK (4 hrs), 10/12/2015.

- ESR9, Preparing for the VIVA, UNOTT, Nottingham, UK (4 hrs), 29/02/2016.
- ESR9, PowerPoint: Creating a research poster, UNOTT, Nottingham, UK (4 hrs), 12/04/2016.
- ESR12, Building a successful academic career, UCD, Dublin, Ireland (2 hrs), 11/11/2015.
- ESR12, Endnote – reference management, UCD, Dublin, Ireland (1 hr), 01/02/2016.

ESR12 and ESR2 at Endnote demonstration in UCD

- ESR12, Academic Written English, UCD, Dublin, Ireland (2 hrs), 26/04/2016.
- ESR12, Seminars on Research, UCD, Dublin, Ireland (15 hrs), 14/10/2015 to 29/04/2016.
- ESR12, Peer reviewer for JoSEM journal, 24/04/2018 and 12/06/2018.
- ESR12, Reading for your thesis, UCD, Dublin (1 hr), 15/05/2018.
- ESR12, Writing habits, UCD, Dublin (1 hr), 18/05/2015.
- ESR12, Writing solid academic essays, UCD, Dublin (1 hr), 21/05/2018.
- ESR12, Member of the local organisation committee of CERAI 2018 conference, UCD, Dublin, 18/04/2018 to 31/08/2018.
- ESR13, Academic writing: Science & Engineering, UNOTT, Nottingham, UK (9 hrs), 26/10/2015 to 23/11/2015.
- ESR13, Academic writing: Grammatical accuracy, UNOTT, Nottingham, UK (9 hrs), 29/10/2015 to 26/11/2015.
- ESR13, How to be an effective researcher, UNOTT, Nottingham, UK (7 hrs), 16/01/2016.
- ESR13, Creative problems exploration, UNOTT, Nottingham, UK (5.5 hrs), 03/02/2016.
- ESR13, Presentation skills for researchers, UNOTT, Nottingham, UK (6 hrs), 08/02/2016.
- ESR13, Preparation and submittal of international research funding proposal titled "Unmanned Aerial Vehicles (UAV) – based automated road inspection and damage detection" to U21 Graduate Collaborative Research Awards, 01/07/2017 to 01/08/2017.
- ESR13, QQI level 6 Project Management Exam, 02/08/2018.
- ESR13, Keeping current with research, UCD, Dublin, Ireland (20 hrs), 01/09/2015 to 10/11/2015.
- ESR14, Building a successful academic career, UCD, Dublin, Ireland (2 hrs), 11/11/2015.
- ESR14, Defining Your Digital Project's Goals and Objectives, UCD, Dublin, Ireland (5 hrs), 11/02/2016 to 11/02/2016.
- ESR14, Making a Map with Google Mapping Products, UCD, Dublin, Ireland (2 hrs), 06/04/2016.
- ESR14, Career planning for researchers, UCD, Ireland (5 hrs), 20/07/2017.
- ESR14, Preparation and submittal of international research funding proposal titled "Unmanned Aerial Vehicles (UAV) – based automated road inspection and damage detection" to U21 Graduate Collaborative Research Awards, 01/07/2017 to 01/08/2017.

Some ESRs had the opportunity to participate in teaching activities (i.e., delivering tutorials, supervising students or carrying out demonstrating duties in Universities) as listed below:

- ESR1, Group Design Project (CVEN30160), UCD, Dublin, Ireland, (24 hrs), 25/01/2016 to 27/04/2016.
- ESR1, Group Design Project (CVEN30160), UCD, Dublin, Ireland, (8 hrs), 25/01/2017 to 15/02/2017.
- ESR4, Tutorial Teaching 2E7 - Engineering and the Environment TCD, Dublin, Ireland (4 hrs), 30/10/2015 to 20/11/2015.
- ESR4, Tutorial 4A6 - Teaching Structures II - Advanced Design of Structures, TCD, Dublin, Ireland (13 hrs), 01/02/2016 to 04/04/2016.
- ESR4, Start supervision of visiting student in work to be underpinned regarding the analysis of offshore wind turbines, 20/09/2017 to 20/04/2018.
- ESR6, Tutorial ANSYS lab for CVEN30020 Analysis of Structures, UCD School of civil engineering (3 hrs), 29/03/2017.
- ESR6, Tutorial ANSYS lab for CVEN30020 Analysis of Structures, UCD School of civil engineering (3 hrs), 05/04/2017.
- ESR7, Supervision of BSc Student, University of Exeter, UK, 16/11/2015 to 15/04/2016.
- ESR7, Supervision of MSc Students, University of Exeter, UK, 06/03/2016 to 17/03/2016.
- ESR7, Supervision of BSc Student, University of Exeter, UK, 05/03/2018 to 01/05/2018.
- ESR12, Peer Assisted Tutoring, UCD, Dublin, Ireland, (35 hrs), 25/01/2016 to 05/06/2016.
- ESR13, Introduction to Blogging and Use of Social Media in SciComm (SMARTI ETN), (1 hr), 24/05/2018.

ESR13 introducing blogging and social media to SMARTI ETN

- ESR14, Tutorial Mechanics of Solids (CVEN20010), UCD, Dublin, Ireland, (36 hrs), 08/02/2016 to 25/04/2016.

4.3 COMMUNICATION SKILLS IN CONFERENCES, WORKSHOPS, OUTREACH ACTIVITIES AND PROFESSIONAL MEETINGS

All ESRs have participated in European and/or International Conferences, workshops or meetings of COST actions or professional associations beyond those with TRUSS partners. Here, ESRs learned from talks by experts in different fields of research, had the chance to build a network, and in most of cases, they practised their communication skills via presentations by PowerPoint and posters of their own work to both the Scientific Community and the General Public.

- ESR1, Poster presentation in Research Exhibition, Earth Institute, UCD, Dublin, Ireland, Outreach, 30/09/2015.
- ESR1, Participation in Science Week 2015: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 10/11/2015.
- ESR1, Civil Engineering Research in Ireland (CERI 2016), Galway, Ireland, Conference, 29/08/16 to 30/08/2016.
- ESR1, CICE, 2016, Hong Kong, China, Conference, 14/12/16 to 16/12/2016.
- ESR1, Presentation in Mount Anville Montessori Junior School, Dublin, Ireland, Outreach, 13/02/2017.
- ESR1, CompTest, 2017, Leuven, Belgium, Conference, 05/04/2017 to 07/04/2017.
- ESR1, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR1, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR1, ECCM, 2018, Athens, Greece Conference, 24/06/2018 to 28/06/2018.
- ESR1, MechComp, 2018, Madrid, Spain, Conference, 09/07/2018 to 12/07/2018.
- ESR1, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR1, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR1, Participation at Horizon 2020 stand in EU contest for young scientists (EUCYS 2018), Outreach, 16/09/2018.

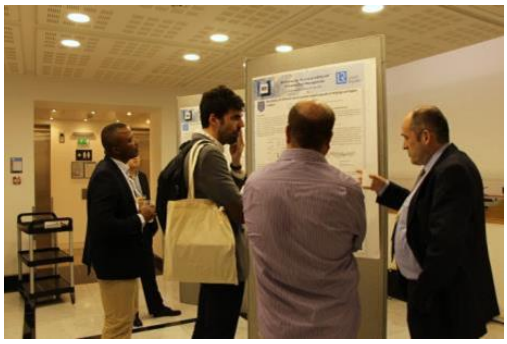
ESR1 at EUCYS 2018

- ESR2, Presentation on non-destructive testing of concrete, Arup, Dublin, Ireland, Outreach, 21/06/2016.
- ESR2, Civil Engineering Research in Ireland (CERI2016), Galway, Ireland, Conference, 29/08/2016 to 30/08/2016.
- ESR2, Participation in Science Week 2016: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 15/11/2016.
- ESR2, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR2, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR2, Participation in Science Week 2017: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 13/11/2017.
- ESR2, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR2, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR3, IYNC 2016, Hangzhou, China, Conference, 27/07/2016 to 29/07/2016.
- ESR3, Civil Engineering Research in Ireland (CERI 2016), Galway, Ireland, Conference, 29/08/2016 to 30/08/2016.
- ESR3, European Safety and Reliability Conference (ESREL 2017), Portoroz, Slovenia, Conference, 18/06/2017 to 22/06/2017.

- ESR3, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR3, Presentation of TRUSS project at Escuela Oficial Idiomas (Language School), Torrelavega, Spain, Outreach, 29/11/2017.
- ESR3, Best Estimate Plus Uncertainty International Conference (BEPU 2018), Lucca, Italy, Conference, 13/05/2018 to 18/05/2018.
- ESR3, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR3, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.

ESR3 in IALCCE2018

- ESR4, Participation in Science Week 2015: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 10/11/2015.
- ESR4, Civil Engineering Research in Ireland (CERI 2016), Galway, Ireland Conference, 29/08/2016 to 30/08/2016.
- ESR4, Participation in Higher Options 2016, Trinity College Dublin, Ireland, Outreach, 14/09/2016.
- ESR4, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.


ESR4 at TRUSS Workshop in UK

- ESR4, European Safety and Reliability Conference (ESREL 2017), Portoroz, Slovenia, Conference, 18/06/2017 to 22/06/2017.

ESR4 at ESREL2017

- ESR4, ICSI 2017, Conference, 04/09/2017 to 07/06/2017.
- ESR4, International Forum on Engineering Decision Making 2018, Conference, 06/05/2018 to 09/05/2018.
- ESR4, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.

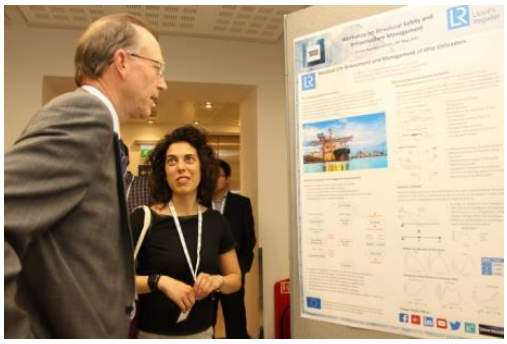

ESR4 at CERI2018

- ESR4, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR5, Technical Investigation Department Technical Brief, GTC, Lloyd's Register, Southampton, UK, Meeting, 19/04/2016.
- ESR5, 18th International Conference on Reliability and Structural Safety (ICRSS 2016), Venice, Italy, Conference, 07/11/2016 to 01/11/2016.
- ESR5, Participation in Science Week 2016: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 15/11/2016.
- ESR5, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR5, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR5, 36th OMAE, Trondheim, Norway Conference, 25/06/2017 to 30/06/2017.
- ESR5, 12th ICOSSAR, Vienna, Austria Conference, 06/08/2017 to 10/08/2017.
- ESR5, Group meeting, Reliability and Risk Analysis Research Group, Aalborg University, Denmark Meeting, 15/09/2017.
- ESR5, Workshop on structural integrity management and NDT in TWI, Cambridge, UK, Workshop, 11/10/2017.

- ESR5, 3rd conference on smart ship technology, RINA, London, UK, Conference, 23/01/2018 to 24/01/2018.
- ESR5, 2nd International Conference on Sustainable Development and Green Buildings (ICSDGB 2018), Xiamen, China, Conference, 01/03/2018 to 03/03/2018.
- ESR5, 28th International Ocean and Polar Engineering Conference (ISOPE2018), Sapporo, Japan, Conference, 10/06/2018 to 15/06/2018.
- ESR5, Civil Engineering Research in Ireland conference (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.

ESR5 at CERI2018

- ESR6, International Conference of Natural Hazards and Infrastructure (ICONHIC2016), Crete, Greece, Conference, 28/06/2016 to 30/06/2016.
- ESR6, European Safety and Reliability Conference (ESREL2016), Glasgow, UK, Conference, 25/09/2016 to 29/09/2016.
- ESR6, Participation in Science Week 2016: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 15/11/2016.
- ESR6, Presentation in Mount Anville Montessori Junior School, Dublin, Ireland, Outreach, 13/02/2017.
- ESR6, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.



ESR6 at TRUSS Workshop in UK

- ESR6, European Safety and Reliability Conference, (ESREL2017), Portoroz, Slovenia. Conference, 18/06/2017 to 22/06/2017.

ESR6 at ESREL2017

- ESR6, X International Conference on Structural Dynamics (EURODYN 2017), Rome, Italy, Conference, 10/09/2017 to 13/09/2017.
- ESR6, 13th International Conference on Steel, Space and Composite Structure (SS18), Perth, Australia, Conference, 31/01/2018 to 02/02/2018.
- ESR6, Civil Engineering Research in Ireland (CERI2018), Workshop, 29/08/2018 to 30/08/2018.
- ESR6, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR6, Technical presentation at Lloyd's Register GTC (Global Technology Center) to report on research outputs, 05/09/2018.
- ESR7, ISHMII Workshop on Structural Health Monitoring of New and Ageing Infrastructure (CSHM-6), Queen's University, Belfast, UK, Queen's University, Belfast, UK, Conference, 26/05/2016 to 27/05/2016.
- ESR7, ICE Bridges Conference, London, UK, Conference, (8 hrs), 01/06/2016.
- ESR7, Structural Health Monitoring and Smart Sensing, seminar presented by Prof Chung-Bang Yun from KAIST and Assoc. Prof. Sung Han Sim from UNIST universities, University of Exeter, UK, Workshop, 04/07/2016.
- ESR7, Are the cultural challenges greater than the technological challenges in realizing an innovative industry?, ICE Debate, Exeter, UK, Meeting, 07/07/2016.
- ESR7, Structural Health Monitoring and Smart Sensing, seminar presented by Dr. Irwanda Laory from the University of Exeter, UK, Workshop, 19/08/2016.
- ESR7, Civil Engineering Research in Ireland (CERI 2016), Galway, Ireland, Conference, 29/08/2016 to 30/08/2016.
- ESR7, Participation in Science Week 2016: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 15/11/2016.
- ESR7, Meeting with bridge owner from West Somerset Railway, Meeting, 15/05/2017.
- ESR7, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR7, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR7, Lecture by Prof. Stana Zivanovic on Interaction between walkers and vibrating structures, Workshop, 27/06/2017 .

- ESR7, Visiting structure lab at the Kyoto University and Meeting Prof. Chul-Woo Kim, Meeting, 02/08/2017.
- ESR7, Presentation by Ph.D. students from future cities laboratory – ethz, Singapore, Workshop, 28/09/2017.
- ESR7, Detecting Hidden Defects in Bridge, ICE Lecture, London, UK, Workshop, 22/11/2017.
- ESR7, Detecting Hidden Defects in Bridge, ICE Lecture, London, UK, Workshop, 10/12/2015.
- ESR7, Civil Engineering Research in Ireland (CERI2018), Workshop, 29/08/2018 to 30/08/2018.

ESR7 at CERI2018

- ESR8, Thesis defense of R. Decatoire and associated workshop, Phimeca, Fédaration Nationale des Travaux Publics, Paris, France, Workshop, 29/08/2016 to 30/08/2016.
- ESR8, Civil Engineering Research in Ireland (CERI2016), Galway, Ireland, Conference, 29/09/2016 to 01/10/2016.

ESR8 at CERI2016

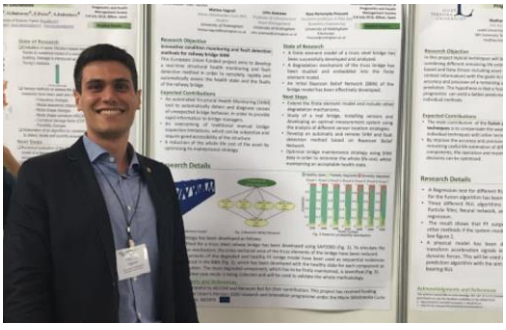
- ESR8, 9th International Conference on Bridges in Danube Basin (BDB2016), Žilina, Slovakia, Conference/Seminar, 20/10/2016 to 21/10/2016.

ESR8 at BDB2016

- ESR8, Participation in Science Week 2016: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 15/11/2016.
- ESR8, 51st ESReDA Seminar, Clermont-Ferrand, France, Conference, 18/06/2017 to 22/06/2017.
- ESR8, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR8, European Safety and Reliability Conference (ESREL2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR8, 3rd International Conference on Vulnerability and Risk Analysis and Management, 7th International Symposium on Uncertainty Modelling and Analysis and the 4th International Symposium on Uncertainty Quantification and Stochastic Modelling (ICVRAM-ISUMA-Uncertainties 2018), Florianópolis, Brazil, Conference, 08/04/2018 to 11/04/2018.

ESR8 at ISUMA2018

- ESR8, Civil Engineering Research in Ireland (CERI2018), Workshop, 29/08/2018 to 30/09/2018.
- ESR8, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR9, Asset management Meeting between Network rail and the University of Nottingham, UNOTT, Nottingham, UK, Meeting, 06/10/2015 to 06/10/2015.
- ESR9, Meeting with Network Rail, Nottingham, UK, Meeting, 03/03/2016.
- ESR9, Meeting with Network Rail, UNOTT, Nottingham, UK, Meeting, 27/04/2016 to 24/04/2016.
- ESR9, Introduction of the TRUSS project to the University of Nottingham students, UK, Outreach, 09/11/2016.
- ESR9, 3rd European Conference of the Prognostics and Health Management Society (PHME16), Bilbao, Spain, Conference, 05/07/2016 to 08/07/2016.



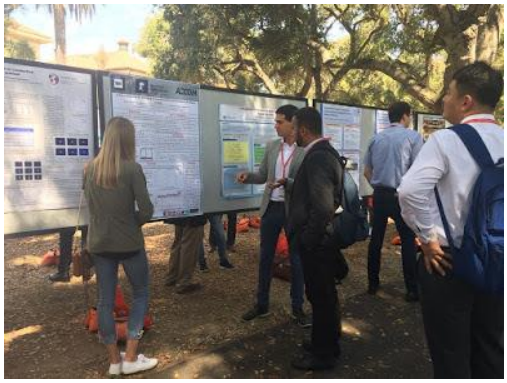
ESR9 at PHME16

- ESR9, The Stephenson Conference, Institution of Mechanical Engineers, London, 25 - 27 April 2017, Conference, 25/04/2017 to 27/04/2017.
- ESR9, The 52nd ESReDA Seminar on Critical Infrastructures: Enhancing Preparedness & Resilience for

the Security of Citizens and Services Supply Continuity, Conference, 30/05/2017 to 31/05/2017.

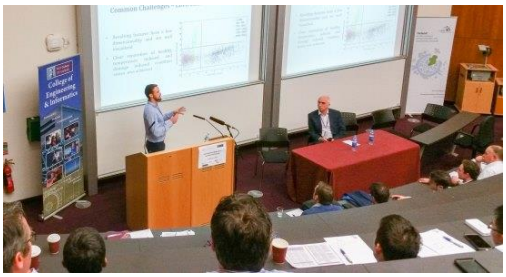
ESR9 at ESReDA

- ESR9, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR9, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR9, Demonstrator at the Open Day in University of Nottingham, UK, 30/07/2017.
- ESR9, 11th International Workshop on Structural Health Monitoring (IWSHM), Stanford, California, US, Conference, 12/09/2017 to 14/09/2017.



ESR9 at the IWSHM conference in Stanford.

- ESR9, Invited speaker at the meeting of the Safety and Reliability Society, Midlands Branch, Workshop, 13/03/2018.
- ESR9, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR10, Summit on Global Risk in Structural Engineering, IABSE and Finnish Association of Civil Engineers, UPC, Barcelona, Spain, Workshop, 11/03/2016.
- ESR10, ISHMII Workshop on Structural Health Monitoring of New and Ageing Infrastructure (CSHM-6), Queen's University, Belfast, UK, Workshop, 26/05/2016 to 27/05/2016.
- ESR10, 8th European Workshop On Structural Health Monitoring (EWSHM), Bilbao, Spain, Conference, 05/07/2016 to 08/07/2016.
- ESR10, Civil Engineering Research in Ireland 2016 (CERI2016), Galway, Ireland, Conference, 29/08/2016 to 30/08/2016.



ESR10 at CERI2016

- ESR10, 5th International Symposium on Life-Cycle Civil Engineering (IALCCE 2016), Delft, The Netherlands, Conference, 16/10/2016 to 19/10/2016.
- ESR10, Gave presentation to a visiting professor (Al Ghorbanpoor de la University of Winsconsin-Milwaukee) on research progress and about the TRUSS project as a whole, Barcelona, Spain, Meeting, 05/04/2017.
- ESR10, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR10, Open Day activity of the doctoral school at UPC, Spain, Outreach, 08/06/2017.
- ESR10, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR10, EVACES 2017, San Diego, California, USA, Conference, 12/07/2017 to 14/07/2017.
- ESR10, ANCRiSST 2017, Tokyo, Japan, Conference, 22/07/2017 to 23/07/2017.
- ESR10, 10th International Conference on Structural Dynamics (EURODYN 2017), Rome, Italy, Conference, 10/09/2017 to 13/09/2017.
- ESR10, Participation in Science Week 2017: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 13/11/2017.
- ESR10, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR10, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR11, 10th International DIANA users meeting, DIANA Users Association, UPC, Barcelona, Spain, Meeting, 29/10/2015 to 30/10/2015.
- ESR11, 8th International Conference on Bridge Maintenance, Safety and Management (IABMAS 2016), Foz do Iguaçu, Brazil, Conference, 26/06/2016 to 30/06/2016.
- ESR11, Summit on Global Risk in Structural Engineering, IABSE and Finnish Association of Civil Engineers, UPC, Barcelona, Spain, Meeting, 11/03/2016.
- ESR11, 3rd COST TU1402 Workshop, Technical University of Denmark, Department of Civil Engineering UPC, Barcelona, Spain, Workshop, 14/03/2016 to 15/03/2016.
- ESR11, ISHMII Workshop on Structural Health Monitoring of New and Ageing Infrastructure (CSHM-6), Queen's University, Belfast, UK, Workshop, 26/05/2016 to 27/05/2016.

- ESR11, 8th European Workshop On Structural Health Monitoring (EWSHM), Bilbao, Spain, Conference 05/07/2016 to 08/07/2016.
- ESR11, COST TU 1402 5th Workshop, Copenhagen, Denmark, Workshop, 24/08/2016 to 25/08/2016.
- ESR11, 5th International Symposium on Life-Cycle Civil Engineering (IALCCE 2016), Delft, The Netherlands, Conference, 16/10/2016 to 19/10/2016.
- ESR11, TRUSS Workshop on Structural Safety and Infrastructure Management, Workshop, 24/05/2017.
- ESR11, Open Day activity of the doctoral school at UPC, Spain, Outreach, 08/06/2017.
- ESR11, European Safety and Reliability Conference (ESREL 2017) at Portoroz, Slovenia, Conference, (24 hrs), 18/06/2017 to 22/06/2017.
- ESR11, ANCRiSST 2017, Conference, 22/07/2017 to 23/07/2017.
- ESR11, X International Conference on Structural Dynamics (EURODYN 2017), Rome, Italy, Conference, (18 hrs), 10/09/2017 to 13/09/2017.
- ESR11, 39th IABSE Symposium, Conference, (18 hrs), 19/09/2017 to 23/09/2017.
- ESR11, Bridge Dynamic Response by Design, Workshop, 20/09/2017.
- ESR11, 9th International Conference on Bridge Maintenance, Safety and Management (IABMAS 2018), Melbourne, Australia, Conference, 09/07/2018 to 13/07/2018.

ESR11 at IABMAS2018

- ESR11, 7th World Conference on Structural Control and Monitoring, Conference, 22/07/2018 to 25/07/2018.
- ESR11, Civil Engineering Research in Ireland (CERI 2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR11, 12th fib International PhD-Symposium in Civil Engineering, Conference, 29/08/2018 to 31/08/2018.
- ESR11, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Ghent, Belgium, Conference, 28/10/2018 to 31/10/2018.
- ESR12, Poster in Research Exhibition, Earth Institute, UCD, Dublin, Ireland, Outreach, 30/09/2015.
- ESR12, Participation in Science Week 2015: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 10/11/2015.
- ESR12, ISHMII Workshop on Structural Health Monitoring of New and Ageing Infrastructure (CSHM-6), Queen's University, Belfast, UK, Queen's University, Belfast, UK, Conference, 31/05/2016 to 31/05/2016.
- ESR12, Civil Engineering Research in Ireland (CERI 2016), Galway, Ireland, Conference, 29/08/2016 to 30/08/2016.


ESR12 at CERI2016

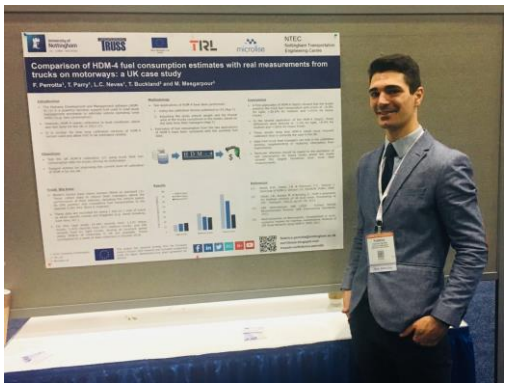
- ESR12, SEMC 2016, Cape Town, South Africa, Conference, 05/09/2016 to 05/09/2016.
- ESR12, ROSE Green Roads Infrastructure, Workshop, 24/11/2016 to 25/11/2016.


ESR12 at ROSE Workshop

- ESR12, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR12, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR12, Participation in Summer School: Wooden Bridge Challenge, UCD, Ireland, Outreach, 27/07/2017.
- ESR12, Participation in Science Week 2017: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 13/11/2017.
- ESR12, Civil Engineering Research in Ireland (CERI 2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR12, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.
- ESR13, Microlise Transportation Conference 2016, Coventry, UK, Conference, 18/05/2016 to 18/05/2016.
- ESR13. 8th RILEM Conference, IFSTTAR, Nantes, France, Conference, 07/06/2016 to 07/06/2016.
- ESR13, Presentation of results at TRL, Wokingham, UK, Outreach, 30/03/2017.

Presentation by ESR13 at TRL

- ESR13, TIS Conference 2017, Rome, Italy, Conference, 10/04/2017 to 10/04/2017.
- ESR13, PLCA Symposium 2017, Illinois, US, Conference, 12/04/2017 to 12/04/2017.
- ESR13, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/2017 to 25/05/2017.
- ESR13, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/2017 to 22/06/2017.
- ESR13, Participation in 1st Open Day UNOTT 2017, Nottingham, Outreach, 30/06/2017 to 01/07/2017.
- ESR13, Presentation at TRL PhD Day 2017, UK, Outreach, 19/07/2017.
- ESR13, Participation in 2nd Open Day UNOTT 2017, Nottingham, Outreach, 15/09/2017 to 16/09/2017.
- ESR13, ROSE Workshop 2017, Workshop, 23/11/2017.
- ESR13, IEEE Big Data 2017, Conference, 10/12/2017 to 10/12/2017.
- ESR13, Transportation Research Board (TRB) 2018, Conference, 07/01/2018 to 07/01/2018.



Poster session by ESR13 at TRB2018

- ESR13, Participation in 1st Open Day UNOTT 2018, Nottingham, Outreach, 29/06/2018 to 30/06/2018.
- ESR13, Transportation Research Arena (TRA) 2018, Conference, 16/04/2018 to 16/04/2018.
- ESR13, Civil Engineering Research in Ireland (CERI 2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.

ESR13 at CERI2018

- ESR14, Poster presentation in Research Exhibition, Earth Institute, UCD, Dublin, Ireland, Outreach, 30/09/2015.
- ESR14, Participation in Science Week 2015: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 10/11/2015.
- ESR14, Presentations at Arup, Dublin, Ireland, Outreach, 19/04/2016 and 31/07/2016.
- ESR14,Technology Day, Korec, Maynooth, Ireland, 01/10/2015.
- ESR14, Drone Developer Workshop, 3D Robotics, Atlantic Bridge, Irish Development Agency, Startup Ireland, and the Linus Foundation's Dronecode Project, Dublin, Ireland, Workshop, 05/10/2015.
- ESR14, Drone Developer Workshop, 3D Robotics, Atlantic Bridge, Irish Development Agency, Startup Ireland, and the Linus Foundation's Dronecode Project, Dublin, Ireland, Workshop, 08/10/2015.
- ESR14, Orientation presentation, School of Civil Engineering, UCD, Dublin, Ireland, Outreach, 07/09/2016.
- ESR14, Drone Workshop, UCD, Dublin, Ireland, Outreach, 29/10/2016.
- ESR14, UCD Computer Science Open Day, Dublin, Ireland, Outreach, 22/11/2016.
- ESR14, TRUSS Workshop on Structural Safety and Infrastructure Management, London, UK, Workshop, 24/05/17 to 25/05/2017.
- ESR14, European Safety and Reliability Conference (ESREL 2017), Slovenia, Conference, 18/06/17 to 22/06/2017.
- ESR14, SFI research careers forum, Dublin, Ireland, Workshop, 22/09/2017.
- ESR14, H2020 Information week, Dublin, Ireland, Conference, 19/10/2017 to 22/10/2017.
- ESR14, VSMM 2017, UCD, Ireland, 31/10/2017 to 05/11/2017.
- ESR14, Participation in Science Week 2017: "Free-standing structure challenge", Willow Park Junior School, Dublin, Ireland, Outreach, 13/11/2017.
- ESR14, UCD Discovery workshop: the Atlantic Bridge POP fund, Workshop, 16/11/2017.
- ESR14, Civil Engineering Research in Ireland (CERI2018), Dublin, Ireland, Workshop, 29/08/2018 to 30/08/2018.
- ESR14, Participation at Horizon 2020 stand in EU contest for young scientists (EUCYS 2018), Outreach, 16/09/2018.

ESR14 at EUCYS2018

- ESR14, 6th International Symposium on Life-Cycle Civil Engineering (IALCCE2018), Conference, 28/10/2018 to 31/10/2018.

ESR14 at IALCCE2018

Further information about local training activities can be found on TRUSS website (http://trussitn.eu/?p=11113).

The TRUSS ITN project (www.trussitn.eu) has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 642453