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<tbody>
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The TRUSS ITN project (2015-19): a Marie Skłodowska-Curie innovative training network on reducing uncertainty in structural safety

Arturo González
1Civil Engineering School, University College Dublin, Dublin 4, Ireland
email: arturo.gonzalez@ucd.ie

ABSTRACT: The structural deterioration of aging structures is often aggravated by an increase in loads that were not foreseen at the design stage and an insufficient maintenance spending as a result of the economic downturn of recent years. A management strategy guaranteeing structural safety with the best use of the resources available is clearly needed. TRUSS (Training in Reducing Uncertainty in Structural Safety, http://trussitn.eu/ 2015-2019) is a €3.7 million Marie Skłodowska-Curie innovative training network funded by the European Horizon 2020 Research and Innovation Programme, with the main objectives of: (1) carrying out research that will ensure structural safety levels for buildings, energy and transport infrastructure, and (2) providing training to a new generation of researchers for dealing with an aging infrastructure stock. The network is composed by 6 Universities, 11 companies and 1 research institute from 5 European countries, joining forces to identify, quantify and reduce uncertainties associated to the structural response, to the imposed loads, and to the probability of structural failure.

KEY WORDS: Structural safety; ITN; Marie Skłodowska-Curie; Infrastructure; Doctoral training.

1 INTRODUCTION

The Marie Skłodowska-Curie Innovative Training Network (ITN) TRUSS was favourably evaluated by the Research Executive Agency and invited to grant preparation in September 2014. Out of 1161 proposals, TRUSS is one the 121 successful projects funded under the H2020-MSCA-ITN-2014 call [1]. Fourteen Early Stage Researchers (ESRs) are funded within TRUSS with the purpose of providing them with a range of research skills related to structural assessment of infrastructure, and also with creative, entrepreneurial and innovative skills that will help them to convert these knowledge and ideas into products and services for economic and social benefit. The ITN scheme extends beyond the traditional academic research training setting by equipping ESRs with the right combination of research-related and transferable competences, which will enhance their career perspectives in both academic and non-academic sectors through international, interdisciplinary and inter-sector mobility [2].

The research theme of TRUSS are buildings, energy and transport infrastructure, which are key elements for supporting society in day-to-day activities. The infrastructure network is ageing and deteriorating rapidly under an increasing demand in operational and environmental loads. While an efficient infrastructure network provides economic and social benefits, infrastructure failure in terms of capacity or reliability can involve economic costs and lower quality of life. For infrastructure to remain effective and structurally safe, a management strategy that guarantees proper maintenance and best use of the resources available is needed. An optimal strategy will minimize costs while ensuring safety levels (Figure 1). However, this is a complex task due to uncertainties associated to the structural capacity and to the demand on a structure.

Figure 1. Variation of repair costs with time.

Therefore, the main objectives of TRUSS ITN are twofold:

• To develop reliable monitoring systems and structural, material and loading models to be achieved through research that will contribute to: (a) more efficient infrastructure design, assessment, monitoring and management, (b) maintain current infrastructure stock in operation while minimizing risks, and (c) reduce infrastructure costs and demand for non-renewable and carbon intensive resources while maintaining or improving safety levels.

• To offer a high-quality intersectoral and multidisciplinary training in structural safety to a new generation of ESRs through network-wide and local activities. The training programme combines taught modules with original research supported by secondments, which allows ESRs gaining experience and enhancing their career prospects in both industrial and academic sectors.

Training and secondment opportunities by the network allow ESRs to be exposed to technologies evolving rapidly, and to research and innovation in both academia and industry. Individual projects fall within two research clusters: (i)
buildings (methods for testing of strength, new materials),
energy (nuclear, wind turbine towers) and marine (off-shore,
ships and ships unloaders) infrastructure, and (ii) rail and road
infrastructure (pavement, railway and highway bridges). A
summary of all individual research projects can be found in
[3]. Some fellows are focused on lab tests to reduce
uncertainty associated to measurement techniques and to
materials. Other fellows are concerned with the development
of efficient structural monitoring systems (i.e., based on
distributed optical-fiber sensing, instrumented drones and land
vehicles). A third group of fellows is developing algorithms
for damage detection, estimation of remaining life and
structural inspection purposes.

Within this framework, the TRUSS proposal involves
partnerships at a variety of levels. At the most basic level,
there is a number of bilateral collaborations, centred around
ESRs. Each ESR is assigned a project with a Doctoral Studies
Panel (DSP) composed by experts from at least two European
countries, including both academic and industrial
participation. TRUSS network brings together a consortium
(Figure 2) consisting of four leading European Universities
with a world perspective on education (University College
Dublin -UCD- and Trinity College Dublin -TCD- in Ireland,
Universitat Politècnica Catalunya -UPC- in Spain, and
University of Nottingham -UNOTT- in UK), and five industry
beneficiaries (Arup in Ireland, Equipos Nucleares SA -ENSAP-
, Full Scale Dynamics Ltd -FSDL- and Lloyd’s Register
EMEA in UK, and Phimeca Engineering in France) with
complementary specialist expertise and enthusiasm for the
prospect of early exploitation of the research results. Six
additional industry partners (Burgmann Packings in Ireland,
COMSA and COTCA in Spain, Greenwood Engineering in
Denmark, and Microlise and AECOM in UK), two
Universities (Université de Nantes in France, and University
of Aalborg in Denmark) and one research institute (TRL in
UK) provide specialised support and secondment
opportunities in specific research projects.

Figure 2. Main interactions at ESR level.

TRUSS is structured into five Work Packages (WPs): WP1
on Management (led by UCD), WP2 on Dissemination and
Outreach (led by UPC), WP3 on Structured Training (led by
UCD), and two Research WPs on buildings, energy, marine
(WP4 lead by UCD), rail and road (WP5 lead by UNOTT)
infrastructures. The outputs of these WPs are reviewed next.

2 WP1 MANAGEMENT AND RECRUITMENT

WP1 deals with deal with the management, governance,
recruitment and mobility of the programme. The ultimate
decision body of the project is the Supervisory Board (SB),
which comprises one representative of all beneficiaries and
partner organizations and an ESR representative for the
purpose of high-level decision-making. Up to date, WP1 has
held 6 management (including SB) meetings. It is worth
noting that the SB has approved the addition of two partners
to the consortium: Universite de Nantes and University of
Aalborg. Regarding recruitment, the total number of
applicants to the 14 ESR positions was 211. The percentage
distribution per gender was 85% male and 15% female.
Typically, applicants would apply to more than one position,
adding to 627 applications. There were 22% EU and 78%
non-EU applicants. The distribution by continents was 60%
Asia, 24% Europe, 11% Africa and 5% America. Following a
selection procedure, each ESR was recruited under a 36
month contract as research staff in one of TRUSS
beneficiaries, which acted as main host. All ESRs are also
significantly exposed to working and cultural environments
different from their employer, via secondments that vary
between 3 and 9 months.

3 WP2 DISSEMINATION AND OUTREACH

WP2 disseminates the novel outputs produced by TRUSS
structured PhD research program via presentations at national
workshops, world’s leading international conferences,
publications in peer-reviewed journals of high-impact factor,
reports made available free online and outreach activities.
So far, TRUSS has published a total of 60 conference papers,
15 journal papers, 21 posters and delivered presentations in 23
countries covering the 5 continents. Two workshops (in UK
and Ireland) and two symposia (as part of ESREL 2017 in
Slovenia and IALCCE 2018 in Belgium) have been organised
to highlight TRUSS progress and achievements.

The website (http://trussitn.eu) has 178 pages viewed 95,649
times by 19,127 new users in 33,652 sessions (averaging 2.84
pages and 2 minutes and 56 seconds per session). It contains
information for the public/wider community about the
project’s aims, activities and material available, external links
to ESR’s blogs, to their publications made available in
repositories, and to other websites containing info of interest.
TRUSS profiles in Facebook (142 followers and 24,398
people reached at https://www.facebook.com/trussitn.eu),
Google+ (71 followers at https://plus.google.com/+TrussITN),
LinkedIn (140 connections at https://www.linkedin.com/in/trussitn/),
Twitter (https://twitter.com/TRUSSITN with 150 followers),
YouTube (22 videos in https://www.youtube.com/c/TrussITN
viewed 6,298 times), SlideShare (1120 views of
https://www.slideshare.net/TRUSSITN/presentations),
ResearchGate (https://www.researchgate.net/profile/Truss_Itn
) and fourteen blogs maintained by the ESRs (hosted in web
addresses from http://esr1truss.blogspot.ie/ to
http://esr14truss.blogspot.ie/ with 125 posts and 32,000
views), have been used to bring awareness on the importance of this research to support a community, region or country.

TRUSS has participated in activities in 6 High and Junior Schools (i.e., Science Week), and in 6 research exhibitions and Open Days at Universities to motivate School and University students to pursue an engineering career. Furthermore, TRUSS researchers have been featured in 4 press releases in mainstream newspapers, magazines [2] and television.

4 WP3 STRUCTURED TRAINING

WP3 governs the provision of appropriate structured PhD training modules for the ESRs, to ensure that the quality of structured training meets best practice and that the training needs of the ESRs, as planned in their Project Career Development Plan (PCDP), are being adequately addressed. The TRUSS training programme is structured in two ways: Supervised research towards a doctoral award (Section 4.1), network-wide (Section 4.2) and local (Section 4.3) training activities.

4.1 Supervised research

Each ESR has a project supervisor who guides them in specialist matters, such as the scientific state-of-the-art, key research tools, and dissemination strategies to support publication in the best international journals. In addition, the supervisor liaise with other participants to ensure that the training weeks are delivering modules appropriate to the ESRs under their supervision; these modules are offered either locally or by a University in the network.

4.2 Network-wide training

ESRs have practised their communication skills, and received academic and industrial training and feedback at network-wide meetings held approximately every 6 months. More specifically, TRUSS has run a training week in Nottingham (30/11-04/12/2015), a plenary meeting in Santander (16-17/06/2016), a training week in Barcelona (16-20/01/2017), a plenary meeting and workshop in London (24-25/05/2017), a symposium in Portorož (18-22/06/2017), a training week (15-19/01/2018), a project management course (11-14/06/2018) and a workshop in Dublin (29-30/01/2018), and final symposium will be held in Ghent (28-31/10/2018). Figure 3 shows the structure of a typical training week delivering intensive, highly focused modules to all ESRs.

![Figure 3. Typical training week.](image)

Core research modules are concentrated during the first two training weeks as these skills are required to undertake research in subsequent years. They include ‘methods of safety quantification’, ‘reliability analysis’, ‘life cycle assessment’, ‘updating of random variables using on-site information’, ‘material modelling, ‘load modelling’, ‘overview of fault diagnostic methods’, ‘structural health monitoring’, vulnerability and risk assessment’, ‘uncertainty quantification and propagation for sensitivity or reliability purpose’, ‘practical reliability engineering’, ‘survival analysis and discrete event simulation applied to reliability’, ‘advanced finite element modelling’, ‘multi-Level MC methods for stochastic analysis and robust optimum design’, ‘reducing uncertainty in structural safety through static NDT’ and ‘reducing uncertainty through the structured expert elicitation’. Communication skills include ‘presentation skills’, ‘How to succeed at interview’ and ‘grant writing – a short guide to survival and success’. Transferable skills such as ‘planning your research’, ‘knowledge management: the path to innovation’, ‘responsible conduct in research and innovation’, ‘working with industry on collaborative research projects’, ‘leadership & people management/managing change’ and ‘career planning for PhD students’ are also delivered. Conversely, core business skills take place in the 3rd training week when results are available and these skills are needed to exploit/communicate them. A list of topics covered are ‘concept to commercialization’, ‘stages of funding. Being investor ready’, ‘entrepreneurship & SME formation’, ‘Intellectual property’, ‘patent searching’, ‘creating organisational structures’, ‘commercialisation and exploitation’ and ‘project management’. The research seminars are interactive sessions that prepare the researchers to present their own work at other national and international events. In the Innovation Workshop, ESRs are given a real case study proposed by industry beneficiaries and they present an oral and written solution to colleagues and experts from industry and academia in an interruptible forum. Within this module the students are introduced to value of technical innovation and problem solving.

4.3 Local training

ESRs receive on-the-job training from the local research group at their host, and at the institution/s where they are seconded. A range of advanced research methods, project management, language courses, transferable skills and communication modules are made available to the ESR locally. By combining local research expertise with appropriate modules in specialist topics, the ESRs acquire all of the requisite skills necessary to conduct the high-level research necessary to achieve their PhD.

5 WP4 BUILDINGS, ENERGY AND MARINE INFRASTRUCTURE

Projects by ESR1 to ESR6 fall within WP4, distinguished by the very aggressive environments that the infrastructure is subjected to (corrosive, radioactive, non-linear structural responses) or relatively high uncertainties regarding materials and modelling. WP4 addresses uncertainties in the response of not-well known materials via lab testing or strength assessment in existing buildings, in the variation of the non-linear dynamic response of sliding structures under water due to differences in the modelling, in the loads and safety of large wind turbine towers and in the remaining life of assets (some operating beyond their original design life) in extreme and harsh marine conditions. The titles of these projects are listed in Table 1.
Table 1. Projects in WP4.

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<tr>
<th>ESR</th>
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<tr>
<td>1</td>
<td>Reliability of concrete structures reinforced with braided FRP</td>
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<tr>
<td>2</td>
<td>Reduction of uncertainty in assessing concrete strength of existing structures</td>
</tr>
<tr>
<td>3</td>
<td>Reduction of uncertainty in design of free standing nuclear spent fuel rack</td>
</tr>
<tr>
<td>4</td>
<td>Probabilistic optimisation of the design of offshore wind turbine towers</td>
</tr>
<tr>
<td>5</td>
<td>A probabilistic framework for fatigue crack management of ship structures</td>
</tr>
<tr>
<td>6</td>
<td>Residual life assessment and management of ship unloaders</td>
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Through a combination of laboratory work and numerical modelling, ESR1 shows that the geometric design plays a significant role on the reliability of concrete structures reinforced with braided FRP [4-9]. ESR2 uses common non-destructive testing methods to assess concrete strength, and finds large variability and influence of scale effects. Instead, a new approach based on the installation of a screw anchor in the concrete is proposed [4,10-12]. ESR3 identifies seven sources of uncertainty in the response of free standing nuclear spent fuel racks. He provides error estimates via a probabilistic analysis [4,13-16]. ESR4 carries out an analysis of univariate significant wave heights. Kriging models are proposed for analysing the towers of wind turbines [4,17-21]. Fatigue plays a critical role in service life assessment of marine structures. ESR5 show how the interval for the first inspection of ageing marine structures can be extended if crack initiation life is considered [4,22-28]. ESR6 reduces the uncertainty associated to dynamic loads employed in assessment of ship unloaders via numerical models and field measurements [4,29-33].

6 WP5 RAIL AND ROAD INFRASTRUCTURE

The infrastructures covered in WP5 are characterized by a variable traffic load. The objectives of WP5 are to reduce uncertainty, improve structural assessments and management of land transport infrastructure via the development of new monitoring/sensor technologies that will allow more efficient data collection, and new algorithms that will process the data collected from the structure to estimate its safety more accurately than current approaches. Table 2 gives the WP5 project undertaken by each ESR.

Table 2. Projects in WP5.

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<tr>
<th>ESR</th>
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<tr>
<td>7</td>
<td>Bridge condition assessment using rotation measurements</td>
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<tr>
<td>8</td>
<td>Probabilistic modelling of bridge damage based on damage indicators</td>
</tr>
<tr>
<td>9</td>
<td>Railway bridge condition monitoring and fault diagnostics</td>
</tr>
<tr>
<td>10</td>
<td>Assessment of bridge condition and safety based on measured vibration level</td>
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<tr>
<td>11</td>
<td>Development of optical fibre distributed sensing for SHM of bridges and large scale structures</td>
</tr>
<tr>
<td>12</td>
<td>Bridge damage detection using instrumented vehicle</td>
</tr>
<tr>
<td>13</td>
<td>Using truck sensors for road pavement performance investigation</td>
</tr>
<tr>
<td>14</td>
<td>Reduction of uncertainty through regularized, automated road infrastructure inspection, using unmanned aerial vehicles</td>
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ESR7 tests the sensitivity of rotation to damage when a bridge is traversed by a moving load, both numerically and experimentally [34,35-37]. The effect of localized damage on the global bridge safety is assessed by ESR8 via Bayesian updating [34,38-41]. ESR9 computes displacements using a finite element model to demonstrate the ability of a Bayesian Belief Network to predict the health state of a bridge [34,42-45]. ESR10 shows that vibration intensity in the form of vibrors exhibit considerable damage sensitivity when tested under ambient excitation [34,46-53]. Experiments carried out by ESR11 test the possible spatial resolution, strain accuracy and long-term reliability of measurements performed with optical fibre distributed sensing for structural health monitoring of bridges and large scale structures [34,54-63]. ESR12 investigates the feasibility of employing sensors mounted on an instrumented vehicle to detect damage while traversing a bridge. Numerical simulations show that a vehicle can detect a change in the curvature response when the bridge is damaged in a noise-free environment [34,64-70]. ESR13 is also using truck sensors, but for road pavement performance investigation, when a Big Data approach has concluded that the impact of road conditions on truck fleet fuel economy is significant [4,71-74]. A customized unmanned aerial vehicle has been built by ESR14 for image-based inspection, and tested in a controlled lab situation, where the 3D reconstruction method has shown a millimetre level precision [34,75-77].

7 CONCLUSIONS

The improved reliability resulting from TRUSS is expected to contribute to more efficient designs and maintenance strategies and to the cancellation of costly and unnecessary interventions in existing structures. The individual projects in TRUSS are quite diverse. Nonetheless, the need to overcome uncertainty in material, load and structural performance represents a core thread that ties the projects together. This has led to interactions between researchers, and to generate innovations that forms the basis of their PhD research. With the help of innovative health monitoring, damage detection, structural simulations and tests, use of new materials and probabilistic assessments altogether, TRUSS will have an impact on: (a) economic activities, by facilitating an early exploitation of research results and avoiding unnecessary repair works via optimization of structures in terms of their entire life-cycle; (b) sustainability, by reducing waste materials during construction and rehabilitation works and by utilizing innovative and environment-friendly inspection, maintenance and rehabilitation methodologies; (c) social terms, i.e., by avoiding road closures in the case of bridge repairs or failure that will lead to longer travel times and increase costs in many economic sectors, and (d) education, science and technology, by connecting research and its real application via experiences such as the academia-industry partnerships existing in every individual project.

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REFERENCES


