Interdisciplinary knowledge transfer and technological applications for assessment, strengthening and...


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Interdisciplinary knowledge transfer and technological applications for assessment, strengthening and monitoring of timber structures in Europe

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Abstract. COST (European Co-operation in the field of scientific and technical research) is the longest running framework for research co-operation in Europe, having been established in 1971 by a Ministerial Conference attended by Ministers for Science and Technology from 19 countries. Today COST is used by the scientific communities of 35 European countries to cooperate in exchanging knowledge and technology developed within research projects supported by national or European funds. The main objective of COST is to contribute to the realization of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a ''bridge'' towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of ''Networks of Excellence''. Another essential objective is the knowledge transfer between the scientific society and industry. It is widely acknowledged that European scientific performance in relation to investment in science is excellent but technological and commercial performance has steadily worsened. The present paper discusses how the COST Action's instruments, from training schools to short scientific missions and workshops have been used within The COST ACTION FP1101 Assessment, Reinforcement and Monitoring of Timber Structures to achieve such objectives.

Keywords: Training, scientific and technological networks, timber products.

1. INTRODUCTION

COST is an intergovernmental framework for European Cooperation in Science and Technology, allowing the coordination of nationally-funded research on a European level, through the establishment of research networks. One of the nine COST scientific domains is Forests, their Products and Services (FPS) under which the FP1101 is funded over 4 years [1].

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The aims and objectives of the FP1101 COST Action, focussing on Assessment, Monitoring and Strengthening (AMS) of existing timber structures have been widely disseminated to the academic and industrial timber community through active participation at international conferences ([2] [3]). The FP1101 objectives are very well aligned with the SHATIS conference series and COST Action FP1101 members have been strongly supportive of SHATIS conferences, participating in large number to both the current and previous edition [4, 5].

When approaching an existing structure, the knowledge of the structural designer is not sufficient to determine its current health condition, its current safety level, its projected life and use and its need for repair, reinforcement or upgrade. This is true of all existing structures irrespective of the material, but particularly true of structures made of timber, an organic material, which is particularly affected by environmental agents and ageing. The competences and skills of an interdisciplinary team are necessary to reach realistic, efficient, and effective judgement of the structural and building performance [6]. The expertise of material scientists, chemists, physicists, computer scientists, electronic engineers, structural engineers and architects, professionals, academics, researchers and industrialists and contractors, are necessary to arrive at the best solution. And if the building is historic, conservators, architecture historians and engineering historians are also required, to help understand the way the structure was conceived and how best can be preserved. Each expert provides his/her contribution to the jigsaw that leads to the assessment and decision making that allows to extend the life cycle of the building or structure a to keep it functional.

Members of the COST Action FP1101 come from 23 countries in Europe, from institutions as diverse as technical universities, architectural departments, national research facilities, forestry departments and wood institutes, design companies, non-destructive testing scientist and consultants, museum conservation department, material research institutes. The objectives of the FP1101 are to disseminate current advances in research in AMS of timber structures across Europe and among different disciplines, so that such advances can be most effectively and rapidly exploited in applied technology and in the construction industry. The choice to focus on existing structures comes from the principal argument developed by the timber community for its increased use in the construction industry: the fact that timber is a sustainable resource and material. [7] If we improve and adapt timber structures to respond to new environmental and manmade loading, then we can really extend and improve these structures performance, their lifecycle costs and hence the sustainability argument.

Within the COST action we have four different instruments to achieve our objectives: dissemination through the publication of state of the art reports (STAR), workshops, training schools (TS) and short term scientific missions (STSM). In this paper we will provide some evidence of how training schools can be used to transfer the interdisciplinary knowledge base to young researchers and to disseminate up to date technological applications.

Table 1: Summary of statistics of organisation of the training school

	WG	Days	Countries	Trainers	Trainees	Non-COST attendees
TS Athens	1	4	12	7+9	29	22+15
TS Mons	1+2	5	16	15+3	31	12+8
TS Nantes	3	3	10	6+2	25	
TS in Galway	2	4	17	6+5	26 +5	6+3
TS in Guimaraes	1+2	4	17	5+4	24	10

In total the FP1101 organised 5 training schools over a period of 18 months between October 2013 and April 2015. Each school had a different theme, matching the dissemination objectives of the cost action and the working groups' goals. More than 130 trainees participated in the five events with lectures and activities delivered by more than 60 trainers, drawn from academia and industry. Some of the statistics of these activities are summarised in Table 1. Once the delivery of TS has been approved by the MC, then its occurrence is advertised on the COST website and on the FP1101 website, so as to make the application process widely accessible. The trainees are selected so as to broaden participation to a large number of European countries, giving priority to young researchers studying for or having recently received a PhD degree, as it is assumed that this category stands to benefit most from such activities. The aim is to disseminate the latest research findings to the new generation of researchers across Europe. Gender balance is also a criterion for determining the trainees' cohort.

In the following sections we provide more evidence of the structure, organisation and learning outcomes of the training schools.

2. THE TRAINING SCHOOLS: TOPICS, METHODS, ACTIVITIES

The complex interaction among the three main topics around which the activities of the COST FP1101 are organised is depicted in figure 1. This can be read vertically downwards to summarise the logical and temporal flow of actions needed to lead to a strengthening decision, including the need for successive iterations, leading to a deeper knowledge, before a decision is made. It can be read from left to right to identify the generic steps and specific elements of knowledge that need to be acquired to perform an assessment; or right to left to identify remit and purpose of different monitoring activities and how they feed information into the structural assessment; finally it can be read circularly to explain the relationships between the three fundamental activities, underpinning the delivery to society of safe existing structures. A complete ontological map of the activities and actors engaged in this industry, would look much more complicated and beyond the scope of this paper. What we want to focus here is on how the 5 TS addressed some of these issues.

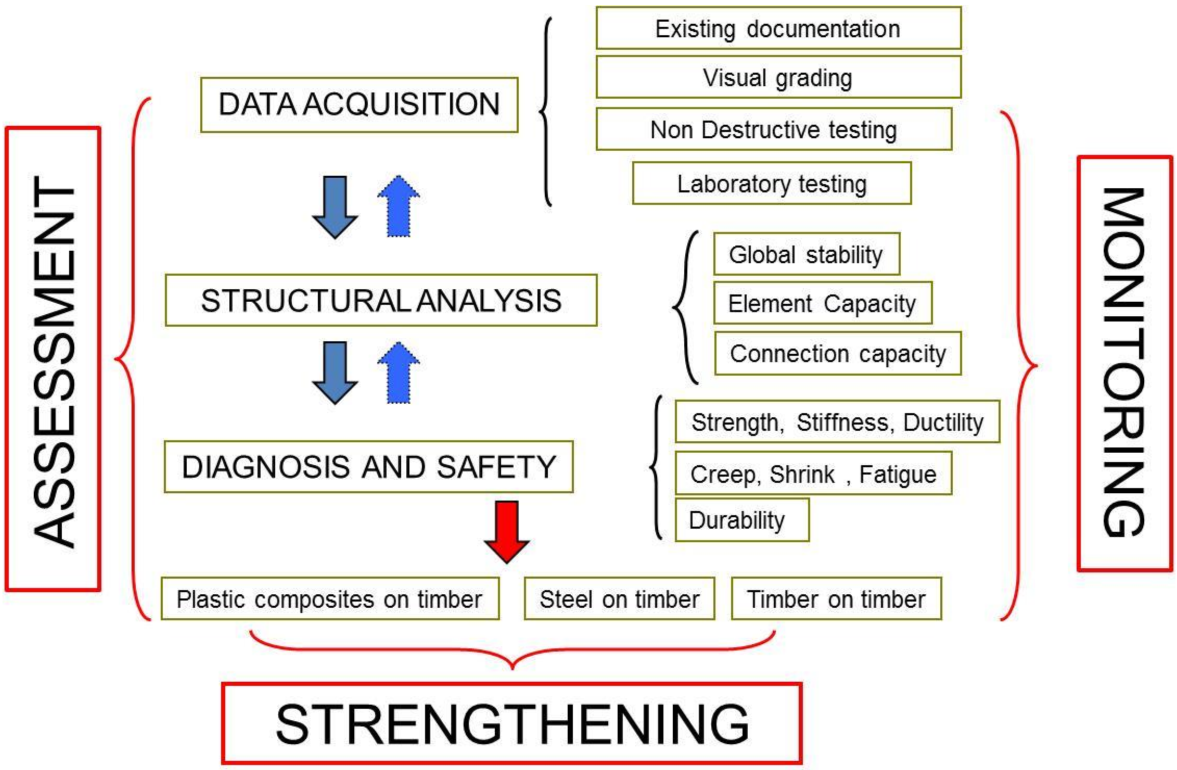

Figure 1: Simplified ontological scheme of activities and knowledge flow

2.1. Onsite Experience: Assessment of historical timber structures, analysis of restoration works: TS in Athens.

The focus of the Athens TS was on historical timber structures, this definition embracing any structures with more than 100 years life or designed prior to the introduction of engineering principles in timber design. The objective was to present all the stages of a restoration project concerning historic timber structures and the need of a multi-disciplinary collaboration during all the stages of such process. [8]. Main attention here was paid on the whole structure and on site activities. The main topics covered during the four days of the school were:

- Survey and construction analysis as a tool for understanding existing structures;
- Non-destructive testing techniques;
- Strengthening methods for single elements;
- Reinforcement of the building against earthquakes using timber;
- Visual inspection and visual grading;
- Structural analysis as an assessment tool.

Figure 2: Historic timber buildings assessment: interpretation of survey drawing, on site design and sizing of repair timber to timber beam connection; implementation of the double scarf joint in a real structure.

An overview of how these topics relate to each other and can be applied from the material scale to the whole building, and represent fundamental tools for the assessment and preservation of historic timber structures [9] The topics were delivered through site visits to buildings of different periods and with different structural arrangements and problems: from a 13th century Venetian roof to a 17th century post-Byzantine era residential building and a more recent, 19th century industrial complex. This variation allowed the participants to gain familiarity with a number of different construction technologies, connection types and problems. Methods for visual grading and application of rudiments of dendrochronology were explained and exemplified. The dissemination of knowledge and interaction was extended to professionals and contractors that work on restoration projects in Greece.

During the sessions on site the conservators contractors applied reinforcing methods under the directions of the trainers, participated in relevant discussions and commented on the reinforcing/repair methods used by them during actual restoration works. Practical demonstration of implementation of reinforcing techniques complemented the analytical topics, delivering also un understanding of what can be done in practice on site, within real structures, when access is limited and the structural safety level might be considerable reduced

2.2. Structural Assessment and strengthening: from global to local: TS in Mons

The need for assessment and reinforcement of timber structures can arise from multiple motivations such as the expiration of their planned lifetime, materials aging, exceptional incidents or a change of use. The assessment of structural members and connections probably is as old as building with timber and closely linked to reinforcement. The development of computational concepts that allow for safe and reliable design of reinforcing measures needs a reliable assessment of timber elements and connections. The TS at Mons followed up closely on the TS held in Athens 2 months earlier, and was complementary to it, focussing on how to improve the assessment of timber members and connections to both estimate their weaknesses and their individual strengths as well as propose suitable reinforcement measures. The TS was an intensive 5 days residential, covering the following topics:

- In situ partial destructive assessment techniques: tension micro specimen, core drilling and resistance drilling;
- Introduction to FRP for timber strengthening: materials, bonding, applications and examples, basis of design, flexural strengthening design, prestressed FRP;
- Assessment and reinforcement of timber columns and beams: notches, holes, reinforcement in support area, wooden reinforcement.
- Assessment and reinforcement of timber composite floors;
- Assessment and reinforcement of connections: doweled connections, old carpentry connections;
- Glued in rods;
- Assessment and reinforcement of timber bridges.

Figure 3: In situ non-destructive testing equipment a)on-site screw withdrawal test, b) on-site core sampling;

demonstration of infrared termographic equipment in the lab; reconstruction of support connection in a truss with glued in rods.

As the list of topics clearly indicates, the aim of this TS was to furnish the trainees with the full set of tools needed to carry out the complete assessment of a timber structure the selection of appropriate reinforcement for each of its parts.

In the two first days of the TS, all non-destructive and semi-destructive testing methods have been presented in relation with the assessment strategy. A detail compilation of NDT methods and their use at different scales and for different purposes for timber structures is contained in [10] including a number of collaborative papers by members of WG1-TG2. For a better understanding, a hands-on session, on-site, was organized in the old timber framings of Mons' town hall. During this session, trainees participated to different tests as for example core testing, tension micro specimen, visual survey, and dendrochronology. In addition, laboratory tests (Resistograph, IR thermography, pin pushing and compression stress-deformation measurements along the timber depth profile) have completed this overview of assessment techniques. These sessions were aimed at identifying the specific structural mechanic characteristics of timber, which are needed in the calculations: stiffness and strength. The trainees had the opportunity to try on a real structure the use of specific equipment developed purposefully for timber, which takes into account the anisotropic nature of the material. These sessions were delivered by practitioners, testing-house staff and wood scientists, bringing together the structural, physical and practical reasons behind in-situ assessment. The second part of the course was devoted to clarify the concepts relevant for the appropriate application of FRP to timber elements: from the issue of bonding to the more recent application of near surface mounted and prestressed bars. The rest of the lectures were then organised to dissect a timber structure in each of its elements, their possible defects and damage, and way to remedy them with reinforcement. Particular attention was devoted to traditional carpentry joints. These are the results of centenary experience and practice, but do not easily accommodate to modern analytical engineering methods. Their assessment follows the so-called component approach, i.e. an assessment of the surface of the carpentry joint in contact, through which forces are exchanged, and how such surface contacts evolve during deformation. This allows understanding of which action are transmitted through the contact, computing stress resultants and determining stress distribution at failure through equilibrium. Such in depth understanding, allows to choose the most appropriate reinforcement if needed.

2.3. Monitoring of timber structures: TS at Nantes

Monitoring of structures is the observation of a structure's behaviour in relation to its condition and the alteration of that behaviour when subjected to all forms of loading or perturbations [11]. While monitoring is typically thought of in the sense of structural health, there are many other areas worth considering, i.e. climate science, seismology, humidity, and temperature measurements related to art and cultural heritage. [12] The development and application of monitoring concepts is essential to the longevity of buildings and infrastructure. The TS in Nantes focused on the third element of knowledge transfer of the FP1101. An introduction to early experiences in timber structures monitoring and its evolution, particularly focusing on the pros and cons of NDT/SDT and their application, was followed by a series of more detailed lectures on the latest developments in non-destructive testing and real time monitoring techniques:

- Ground penetrating radar and applications to timber
- Ultra-sonic testing of timber structures
- Acoustic echo monitoring
- Monitoring systems and concepts
- Dynamic testing of timber structures
- Global energy consumption and environmental monitoring
- Monitoring of timber connections: from wireless data to internet concepts

A comprehensive overview of the state of the art and research activities relevant to the content of this TS has recently been compiled by members of the WG3 [13]. The topics were delivered by a mixture of ex-cathedra lectures and hands-on laboratory activities. The first section on Ultrasonic Radar applications to timber was an opportunity to use specific equipment developed for timber elements [14]. The second hands-on section was to observe and study in situ the health monitoring system of the three-floor structure composed by wooden trusses and composite concrete-wood slabs of the Ecole Superieure du Bois de Nantes. This building has been equipped with different sensors to follow the structural and thermal behaviour during its whole service life. The structural response is measured statically, through strain gauges and temperature/moisture sensors; and dynamically, through accelerometers. One of the objectives of the working group 3 is to define a general protocol for the Structural Health Monitoring of such type of timber structures. This hands-on session represent a first assessment of such protocol. The last hands-on session was on long-term measurements of environmental factors and moisture content in timber elements.

Figure 4: Details of application of ultrasonic radar to laminated timber elements at the TS in Nantes.

2.4. Reinforcement of timber structures: TS in Galway

The TS school in Galway had as objective to link more closely and look more in depth at some of the topics that were introduced at a more generic level in the first two training schools. The focus of this school was on the reinforcement of timber structures using self-tapping screws and glued-in rods. A collection of papers devoted to this subject can be found in the recently state of the art report published by the FP1101 WG2 [15]. The aim was to clearly show how to undertake structural design of reinforcement solutions for different situations. Hence after a detailed introduction on types, mechanical characteristics and behaviour of self-tapping screws and glued-in rods, a session on general design rules as available in the codes or proposed as a results of the STAR of the WG 2, the detailed design of reinforcement was considered for the following configurations:

- Notched, double tapered, curved, pitched cambered beams
- Beams with holes

- Flexural and shear enhancement of beams
- Compressive stresses perpendicular to grain
- Connections

The TS was organised following a design-build-test format with lectures in the morning on a range of reinforcement techniques including self-tapping screws, bonded-in rods, and concrete-timber floor toppings. Experimental tests were performed in the afternoon on joints reinforced using the techniques which had been presented in the morning sessions and had been used for the design. After the experimental tests, attendees performed calculations to verify the reinforcement methods on the basis of the test results. This was carried out in small groups, with direct support from the morning lecturers to clarify aspect that raised questions.

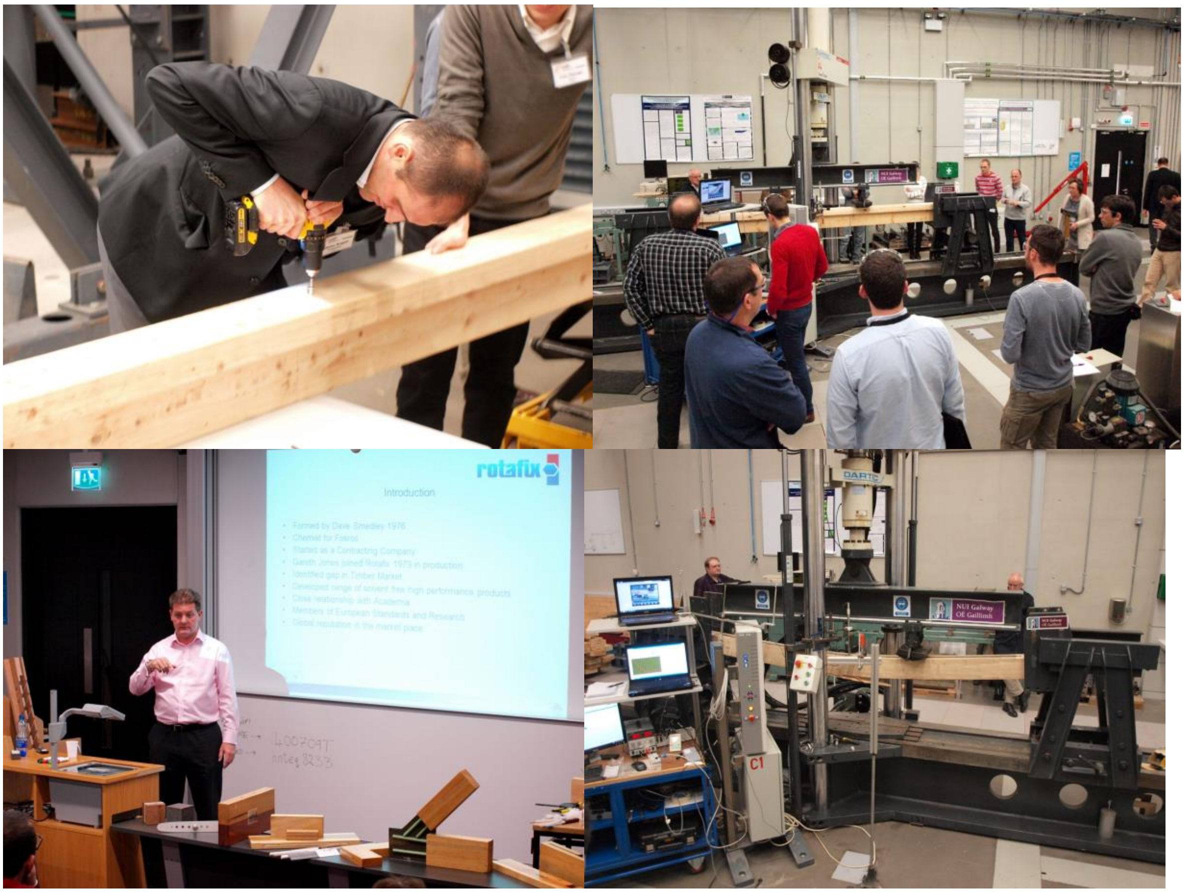

Figure 5 Testing of beams reinforced with self tapping screws and with near surface mounted rods

2.5. Assessment and Reinforcement of Timber Elements and Structures through laboratory testing: TS in Guimarães

The Guimarães TS focused on assessment and reinforcement techniques of historic timber structures and structural members mostly via laboratory work. A historic timber truss that had been recently removed rom an historic building due to heavy material deterioration at the end joints was tested under different loading schemes and up to failure. Also a variety of full scale new carpentry joints (dovetail connections with and without dowel, and single notch joints) were tested to compare these with the behaviour of similar joints within the truss. Then, the participants were introduced to different reinforcement techniques and materials, and asked to decide which reinforcement method would be best to apply before retesting the retrofitted truss and connections.

Four topics were delivered over four days:

- Assessment Visual inspection and grading
- Trusses and Joints Analysis
- Reinforcement
- Full-scale tests

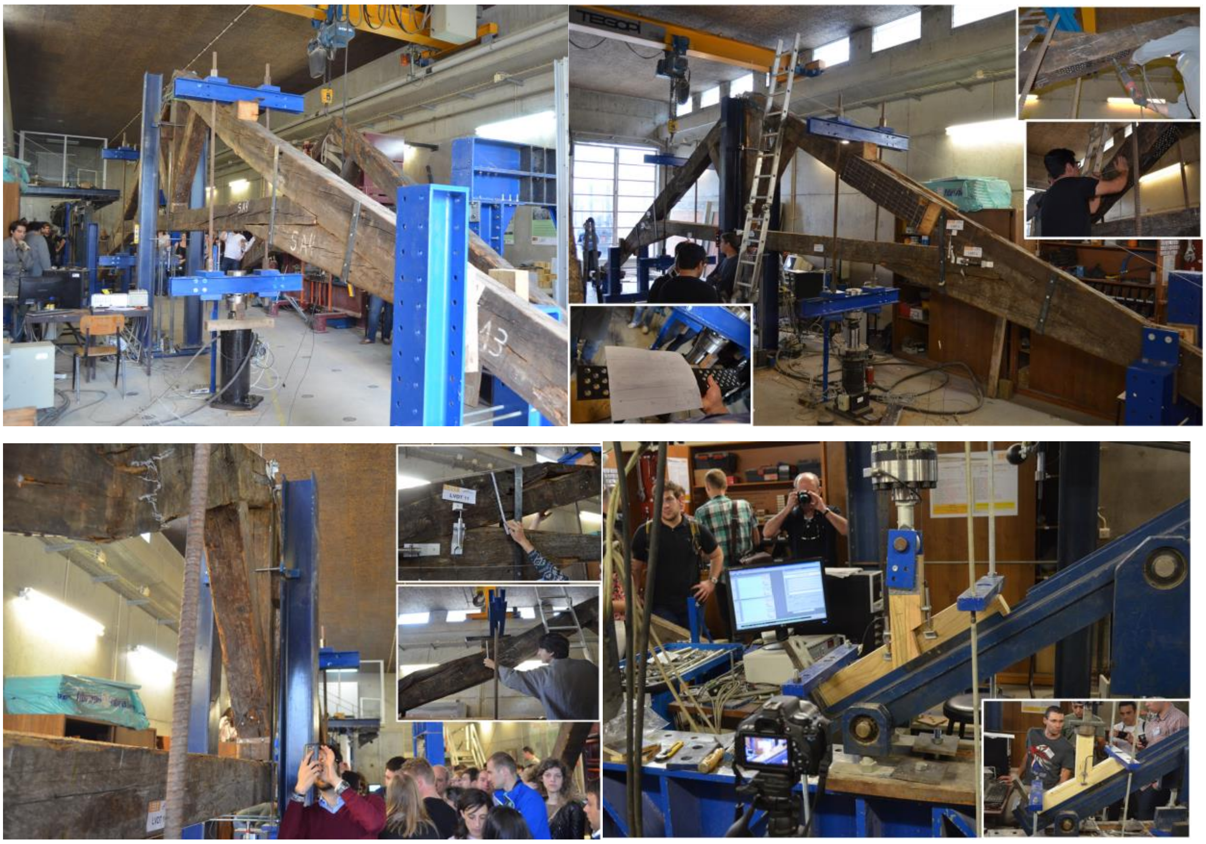

Figure 6 : TS in Guimarães, from top left: testing of existing decayed truss, reinforcement of the truss where the structural failure occurred. Testing of the reinforced truss, and testing of new carpentry joint.

3. LEARNING OUTCOMES, RESOURCES, FEEDBACK

In all TSs, the learning material was prepared and delivered by a highly interdisciplinary team composed of civil engineers, architects, archaeologists and wood technologists. This helped the participants to understand the main focus of each discipline and underlined the need for close collaboration and interaction. Through the five TS trainees acquired a clear insight about visual grading, non-destructive techniques, such as ultrasonic velocity, Pilodyn and Resistograph, different methods for the structural analysis and assessment of structural members, their timber components and their conenections, different types of reinforcement.

In the TS of Galway the trainees developed knowledge of the principles and practise of the reinforcement of timber structures using self-tapping screws and bonded-in rods. The added value was in the joint delivery of theoretical basis of design and recommendation, best practise recommendations and application to real case studies. In the TS in Guimarães, a similar approach was taken, this time comparing directly design of reinforcement with its performance by laboratory testing, in relation to a full-scale typical roof truss.

For all TSs, trainees were provided with soft copies of the presentations and other educational materials such as a design manual containing design exercises and calculation examples. In all TS trainees were required to perform hands-on activities to familiarise themselves with techniques, methods, issues of application, limitations and alternatives. They were also required to undertake and complete design exercises at the end of each day of lectures, to reinforce their knowledge. Moreover, the attendees had an opportunity to experience laboratory testing procedures in accordance with European Standards. Trainees received a certificate for attending the each of the training schools additionally ECTS-credits were allocated for the trainees who submitted extra homework. Only a minority of the trainees took advantage of this opportunity.

Feedback from trainees was indeed extremely positive. They all appreciated the very intensive nature of the school and the very friendly approach of the trainers. The residential format adopted for all TSs, meant that people were facilitated in networking, trainers were available throughout the TS period, and informal clarification, discussion and reflections on the activities of the day were easily stimulated. The fact that the theory explained in the morning sessions, was then demonstrated experimentally in the afternoons made it more memorable. This also aided the understanding and specific relevance of the analytical calculations, which were setup as design and check sessions, to assess the behaviour of the elements tested. In relation to the TS school in Galway, the tutees felt that attending the course, not only strengthen their ability to design reinforcement solutions for a number of different situations, but most importantly they became aware of limitations and secondary effects of the reinforcement. The practical experimental aspect of the course demonstrated the failures visually making apparent the mode of failure of the unstrengthened and strengthened connections.

4. CONCLUSIONS

According to the COST Action Vademecum, „Training Schools aim at widening, broadening and sharing knowledge relevant to the Action’s objectives through the delivery of intensive training on a new and emerging subject. They can offer familiarisation with unique equipment or expertise that are typically to the benefit of ESR, although not exclusively”. [16] .

We consider that the five TS organised by the FP1101, with a total participation of more than 150 early stage researchers and more than 50 trainers, coming from more than 23 countries, including some outside Europe, completely fulfil the aim set out by the COST Association and meet the criteria for a successful outcome. However it is appropriate to ask what are the real benefits of these activities in the medium and long term, beyond the grant period?

From a purely economic viewpoint, COST supports the organisational costs of the TSs, by covering the travelling and subsistence expenditures of everybody attending, as long as residents of member countries, and some of the local organiser’s costs. However the time spent for the preparation of the event, or the time spent by the trainers in preparing and delivering the courses are explicitly excluded from the COST budget. This activity hence relies entirely on the good will of the trainers to deliver their material, as it is the case for many other of the COST activities. Within the FP1101, more than €100000 was allocated to support the TSs, approximately 20% of the total budget of this Action. However a simple calculation of the hours of lecture and demonstration delivered shows that at least an equivalent in kind €50000 were contributed by the organisers and trainers, without considering the logistics resources contributed by the institutions hosting the TSs and the in kind resources offered by industrial and other institutional partners, sponsoring some of the activities.

This compares favourably with the cost of STSMs, where training 20 early stage researchers for periods ranging from 10 days to 3 months, required an average budget of € 2500 each. The benefit of the TSs is appreciated even better if it is considered that an average continual professional development (CPD) course of the same postgraduate level, delivered commercially, would cost €350 per day per attendee for a total equivalent cost of €190000 having assumed an average attendance of 27 trainees per TS for a total of 20 days delivered, without considering the travel and subsistence of the attendees.

But without doubt the most important legacy of the TSs, is the body of knowledge collected in the teaching materials created specifically for these events. These cover more than 160 hours of slides, notes and videos, collated in a systematic way and supplemented by journal papers, conference contributions manuals, handouts and other documentation from project and tests protocols.

This is a substantial resource of knowledge which has been collated on the FP1101 website [1]. We are currently in the process of ensuring broader dissemination of the Training Schools' materials by making all these documents fully accessible to the public.

Beside the substantial and complementary training on different aspects of timber material and structures, The TSs have been an excellent way to bring researchers working in the same field together to share experience and initiate future collaborations. The network of early and more seasoned researchers that has been established through the COST action, is possibly the most beneficial and long lasting outcome of this Action.

In some cases the interaction taking place in the TSs had also the important role of stimulating new conversation among researchers resulting in the organisation of short term scientific missions. In others they contributed to the identification of specific topics needing further work and the setting of task groups, as in the case of WG1-TG3 on the documentation, classification and assessment of carpentry joints, which was instigated as a result of discussion emerging from the first two Training schools.

Figure 7: Members of the FP1101 Cost Action participating to the Training Schools

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REFERENCES

[1] www.costfp1101.eu.
[2] D'Ayala D., Branco J., Riggio, M., Harte, A., Kurz, J., Descamps, T., 2014, Assessment, reinforcement and monitoring of timber structures, Proceedings of the 2nd International Conference on Protection of Historical Constructions (PROHITEC'14)
[3] D'Ayala D., Branco J. , Riggio M., Harte A., Kurz J. , Descamps T. Assessment, Reinforcement And Monitoring Of Timber Structures: Fps Cost Action Fp1101. SAHC2014 – 9 th International Conference on Structural Analysis of Historical Constructions. Mexico
[4] Piazza M., Riggio, M. (eds.) 2013. Structural Health Assessment of Timber Structures, , 2nd International Conference on Structural Health Assessment of Timber Structures (SHATIS 13), September 4-6, 2013, Trento, Italy, pp.1140 Advanced Materials Research Vol. 778 ISBN-13:978-3-03785-812-7
[5] Jasienko J., Novack, T., (eds.) 2015. Structural Health Assessment of Timber Structures, 3nd International Conference on Structural Health Assessment of Timber Structures (SHATIS 15), September 9-10, 2015, Wroclaw, Poland
[6] D'Ayala, D. F., & Forsyth, M. (2007). What is conservation engineering? In M. Forsyth (Ed.), Structure and Construction in Historic Building Conservation (pp. 1-11). Oxford: Wiley-Blackwell
[7] http://www.forestry.gov.uk/england-sustainabletimber
[8] H. Cruz, D. Yeomans, E. Tsakanika, N. Macchioni, A. Jorissen, M. Touza, M. Mannucci, P.B. Lourenço, (2015) Guidelines for the on-site assessment of historic timber structures, Int. J. Archit. Herit., 9 (2015), pp. 277–289
[9] D. D'Ayala, M. Riggio Special Issue: Assessment of historical timber structures–Selected papers from SHATIS13 International Journal of Architectural Heritage, 2015
[10] Machado J.S., Riggio MP., D'Ayala D.F., (eds.) Assessment of structural timber members by non- and semi-destructive methods, Special issue Construction and Building Materials, 2015
[11] SHM Encyclopedia: Encyclopedia of Structural Health Monitoring, Wiley & Sons Ltd, 2009.
[12] Kurz et al. Condition Assessment of Civil Infrastructure in Europe – Recent Developments and What Might Be Ahead, J. Eng. Mech. Vol.139 (2013), No.6, pp.702-711 doi: 10.1061/(ASCE)EM.1943-7889.0000317
[13] Jochen H. Kurz (ed.) Monitoring of timber structures, Journal of Civil Structural Health Monitoring , April 2015, Volume 5, Issue 2, p 97
[14] M. Krause, U. Effner, T. Nowak, S. Müller, D. Vergin, (2013) 3D-SAFT Imaging von Streuern in Brettschichtholz, 2013 DGZFP-Jahrestagung, Dresden, Germany2013
[15] A. Harte, P. Dietsch, (Eds).Reinforcement of Timber Structures. A State-of-the-Art Report', Shaker Verlag, 2015.
[16] Cost Association, Cost Vademecum, May 2015, www.cost.eu/Vademecum