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ASSESSMENT, REINFORCEMENT AND MONITORING OF TIMBER STRUCTURES: FPS COST ACTION FP1101

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Abstract. *Interest in extending the life of existing and historic timber structures has increased steadily in the last decade, owing to a shift in emphasis forward sustainability and low carbon emission of the construction industry. This increased interest and the growing number of researchers and institutions active in this field are the motivation for the setting of COST ACTION FP1101 on assessment, reinforcement and monitoring of timber structures, now nearing completion of its second year of activity. The paper explains what a COST Action is and presents the aims and objectives of this European Research network initiative. It discussed the state of the art in these three fields of research activities as outlined by the work developed jointly by the network. It discusses avenues for further international collaboration beyond Europe by using some of the implementation instruments available within the COST framework. The paper concludes with a discussion on the current research gaps identified through the network workshop, and a view as to how the major outcomes of the network activities can be further disseminated and find institutional outputs through collaboration with RILEM and European Standardisation Technical Committees*

1 INTRODUCTION

Timber, like masonry, has been used as a structural material by mankind since the early beginning of civilization. Although more perishable than masonry, famous and striking whole timber structures have survived from ancient times and many are in use today. Historically timber was used for large span roofs which could be covered by using single timbers connected by carpentry joints, to form complex composite structures, to build temples, such as the ones still surviving in China, or churches, such as the stave churches in Norway or the log churches in Romania or South America (Figure 1), and of course for ships.

Figure 1: Stave churches in Norway, log churches in Maramureș, Romania, Church in Chiloe',Chile.

The last decades were marked by a revival of the material because of its perceived greater sustainability, compared with concrete or steel, a widening in the range of application of timber in construction, to cover major structural forms, and also a steady increase in the heritage and architectural value associated with historic timber structures. Maintenance and preservation of timber structures requires robust structural assessment procedures, specific to the material and the construction details. The need for assessment, reinforcement and monitoring of timber structures can arise from expiration of the planned lifetime, materials aging, threat posed by natural hazards, change of use or of environmental conditions. The time and cost involved in structural assessment are justified by ensuring safety, protecting investments and heritage values by minimizing the need for intervention. (ISCARSAH Principles, 2003)

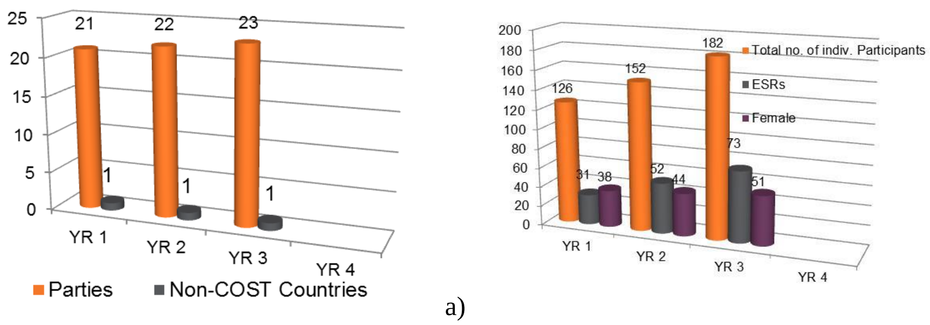
A wide variety of methods exist to evaluate timber structures, however, most assessment methods can give qualitative information about the state of in-situ timber structures, but only few provide reliable quantitative information [1,2]. Methods are usually classified as either non-destructive (NDT), useful for the screening of potential problem areas and for a qualitative assessment of structural performance or health, but unable to allow determining a direct correlation between the observed quantity and the material's mechanical parameters, or as Semi-destructive (SDT), often requiring the extraction of small samples of material for laboratory testing so that calibration of the instrument and characterization of the material can be established while preserving the member's integrity. One problem of SDT is the high variability in test observations. Material characterization is necessary to apply analytical assessment method to establish performance behavior of a structure and determine the need for strengthening, which may be arising from various requirements such as change of use, deterioration, exceptional damaging incidents, new regulatory requirements, or interventions to increase structural capacity.

Recent developments related to structural reinforcement [3-8] can be grouped into three categories: (i) addition of new structural systems to support the existing structure, (ii) configuration of a composite system (timber-concrete, timber-steel, timber-FRP, and timber-timber), and (iii) incorporation of reinforcing elements to increase strength and stiffness. Rational guidelines are needed for these technologies for in-situ use and special considerations are necessary when the structure belongs to cultural heritage.

The monitoring of timber structures received special attention after the collapse of the ice rink in Bad Reichenhall, Germany, in 2006 [9], just one example of a series of structural failures [10]. Structures are being monitored: i) during structural renovations where the acquired data is used to provide the basis for further action; ii) to acquire information when progressive phenomena are suspected; iii) to prevent or reduce the cost of interventions during building maintenance; and iv) to evaluate the long-term effectiveness of interventions. Although recent developments focus on simple, robust and redundant systems [11, 12], the monitoring of timber structures mostly consists of regular on-site visits [13, 14] linked to assessment needs.

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 [15]. The FP1101 Action benefits from multidisciplinary views of the problems, as its membership includes material scientists, structural engineers, researchers involved in conservation of historic timber structures, academics involved in novel products development and application, industrialists and contractors, and the approach adopted is to establish multidisciplinary task-groups focusing on specific topics identified as in need of further harmonization. The Action is aimed primarily at European economic and societal needs, but also establishes links with non-European countries. Currently 23 European and near-Europe countries are participating in the action, while a collaboration link is established with New-Zealand. The Action, led by Dr. Dina D'Ayala, University College London, is organized in three main streams of activities organized in Working Groups which mirror the typical process followed when aiming to extend the life in service of a timber structure: WG1, Assessment, WG2 reinforcement and WG3 monitoring. Figure 2 a) and b) shows the statistics of members involved.

For an overview of the action structures the reader can refer to [16] and [17]. In this paper the attention is focused on specific ongoing activities and achievements of relevance to the Conservation of Heritage Structures. A final section announces future activities and opportunities to participate.



a) b)

Figure 2: Statistics of countries and participants to the FP1101 Cost Action for the three years of activities.

2 ACHIEVEMENTS

The main measure of success of the Action is the ability to provide through its network international platforms to disseminate knowledge through a number of instruments available through the COST framework: (i) State of the art reports outlining the current knowledge and needs for future research; (ii) Conferences and workshops; (iii) Training Schools, and (iv) Short Term Scientific Missions. More details on the full activities carried out by the Action within this framework can be viewed at [15]. A summary of activities and overview of members participation is presented in Table 1 for each Working group. In the following section we will highlight four specific activities which have led to particularly interesting results:

- The development of vulnerability assessment forms
- The development of a Decision Support Tool for Reinforcement Selection
- The catalogue of carpentry joints and appropriate assessment methods
- The training school in Athens

Table 1: Statistics of countries and participants to the FP1101 Cost Action for the three years of activities.

Measures at May 2014	WG 1	WG 2	WG 3	Total
Number of members	84	56	42	182
Number of publications produced by the COST members since the FP1101 inception	109	25	29	163
STSM	6	4	2	12
Workshop participants, Wroclaw, Poland	28	16	11	52
Workshop participants, Telc, CZ	16	21	5	42
Workshop participants, Trento, Italy	37	25	13	75
Workshop participant in Antalya, Turkey	18	21		39
Postgraduate research students advised by COST members	32	30	34	96
Trainees registered for Training school in Athens				27
Trainees registered for Training school in Mons				31
Trainees registered for Training school in Nantes				25

2.1 The Vulnerability Assessment of Historic Timber Frames

While several template and methods are available in literature and among professionals to carry out assessment of historic masonry structures to determine their vulnerability to seismic actions, no equivalent is available for timber structures.

At the meeting in Trento, in September 2013, the TG1 leader Eleftheria Tsakanika (School of Architecture NTUA, Athens, Greece) presented a first draft proposal of an inspection template to beused as a preliminary document to develop "vulnerability assessment forms". Maria Adelaide Parisi (Politecnico di Milano, Italy) described the form developed by her research group, for the seismic vulnerability assessment of timber roofs [18]. Other possible forms could be developed for different timber structure types and differing hazards. In order to further this debate a session was held on "Vulnerability Assessment of historic timber frames" with presentations by early stage researchers members currently involved in studying this topic across Europe. The presentations highlight the differing structural behaviour of the timber framed structures, but also point out to the resilience of some of the historic frames in different Mediterranean areas. These differences, and the positive aspects, should be included in the planned development of "vulnerability assessment templates", so as to identify also resilience indicators. The document has been further developed during a dedicated meeting in London, in February 2014, during a joint meeting with experts of the Working Group 10 of the CEN/ TC 346 on historic timber structures [19]. As a result, a comprehensive list of items characterizing existing timber structures and their typical damage and failures has been drawn (see Figure 3 and 4). Particular emphasis is given to the correlation of causes of damage and specific structural consequences in term of type of failure. The document is currently under final review and will be forwarded to all members of the WG1 of the COST ACTION. In the pilot stage, WG1 experts will assess the completeness, clarity and usefulness of the template structure and of the single items, and eventually revise the form. For this purpose, they will use the form to report on selected case-studies. An additional expected outcome of the filled form is a database of typical structural failures and damage occurring in specific timber structures. This database is not intended to be exhaustive. However, it can be the base for further research, aiming at the development of vulnerability assessment criteria for different types of timber structures.

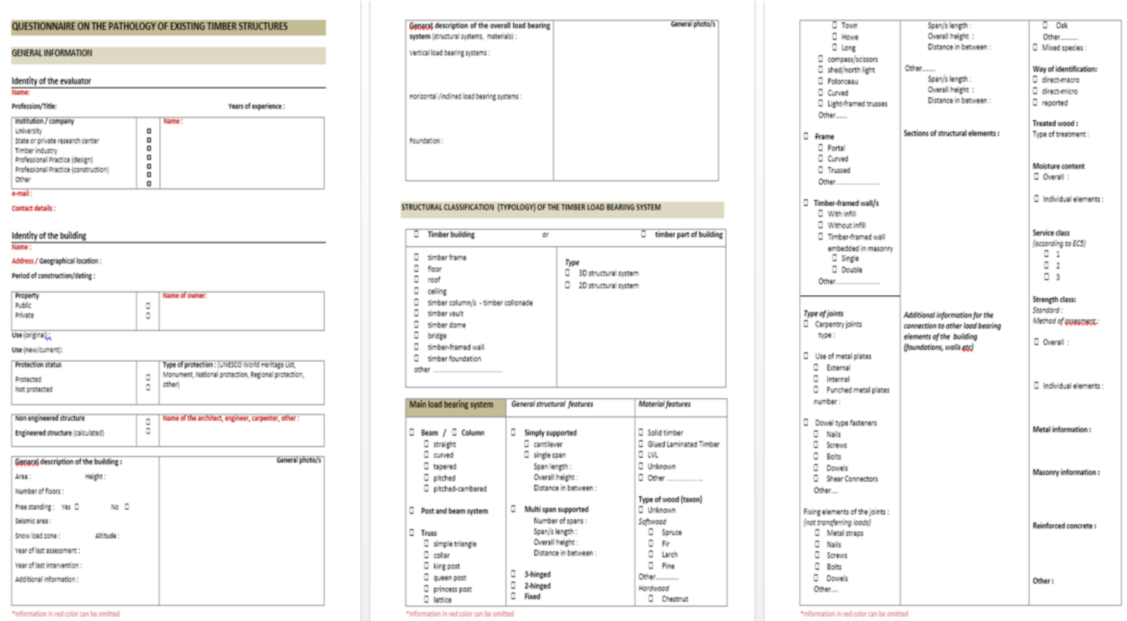


Figure 3: Descriptive part of the template to record the structure and all its elements.

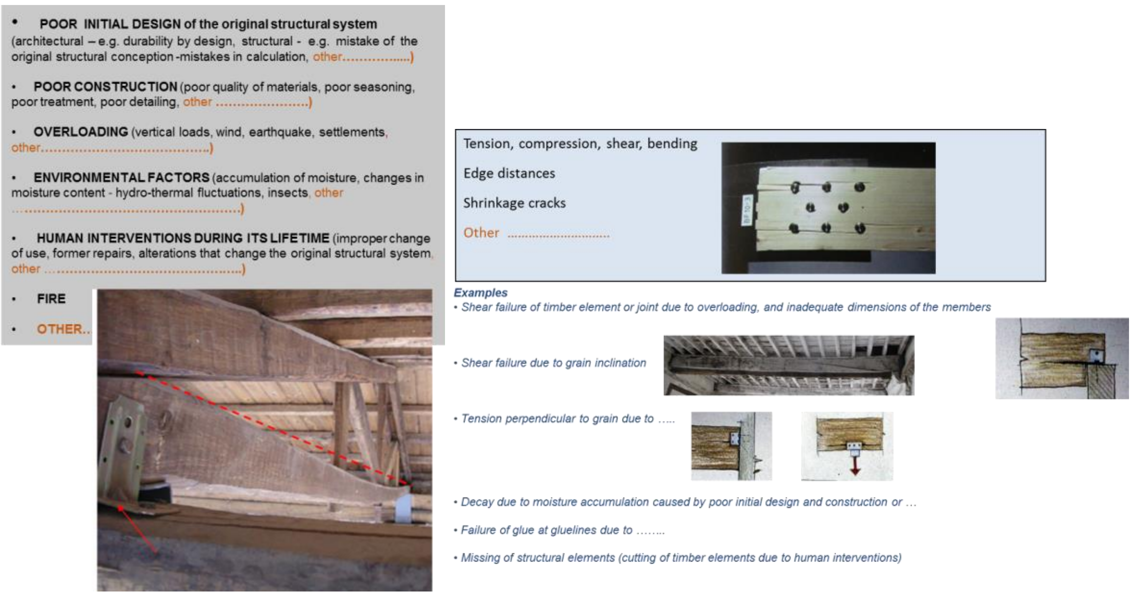


Figure 4: Second part of the template to record damage defects, assumed cause and structural consequences.

2.2 The development of a Decision Support Tool for Reinforcement Selection

During the preparation of the state of the art report (STAR) of the Working Group 2 on the reinforcement of timber structures, it became clear that the types of damage and the range of possible repair/reinforcement solutions for each case were very large. The selection of the optimal repair strategy for any particular scenario is a complex process involving the evaluation of different alternatives under a range of often conflicting criteria. In order to assist engineers and architects to select the 'best' solution among a range of alternatives, it was decided to develop an IT-based decision support tool (DST) to provide the user a range of solutions for a particular problem which have been sorted and ranked according to a range of criteria. Ranking is carried out using least-cost multi-criteria decision analysis.

A prototype tool, *TimberSave*, has been developed as an App for Android platforms using a Short Term Scientific Mission (STSM) exchange between National University of Ireland, Galway and Basque Country University, Spain [20]. The general methodological approach is shown in Figure Based on the outcomes of the assessment of the structure, the tool classifies the damage as biotic, abiotic or mechanical. This part will be further refined and expanded in future taking into accounts results of the work illustrated in section 2.1. Based on the type of damage and the component under consideration, a range of reinforcement solutions is extracted from a database of solutions. These are then ranked according to user-selected weightings of the relative importance of the different criteria for their structure.

Surveys of expert members of COST FP1101 are being carried out to define the range of criteria used. Current criteria include economics, cultural heritage/architectural, environmental. This list will be expanded when the survey results have been analysed. The database will be populated with data from the Vulnerability assessment database by WG1-TG1 and with solutions from the Reinforcement STAR. The App is currently restricted to timber roof structures. Future developments will include adding other structure types to the App and the development of a Decision Support System that will incorporate an Assessment Tool, a structural analysis tool linked to the Reinforcement DST App.

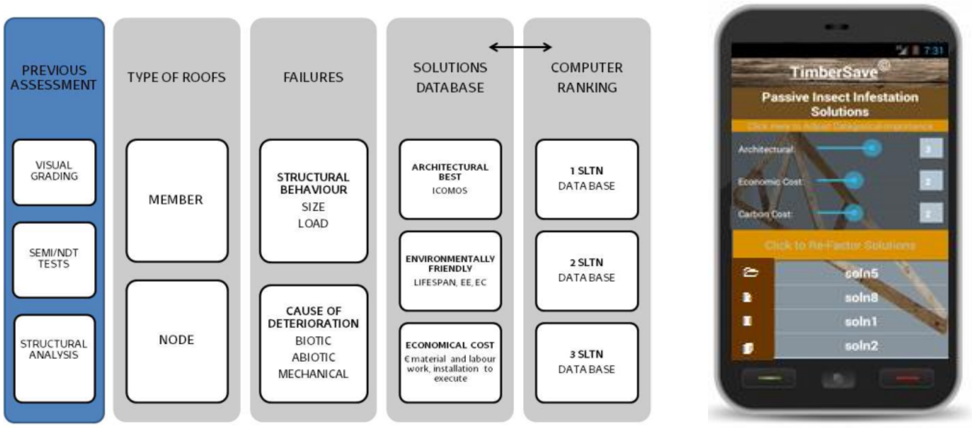


Figure 5: a) methodology and overall structure for the decision making tool; b) the App version for Android

2.3 The catalogue of carpentry joints and appropriate assessment methods

The activity of TG3 stems from the awareness of the large number of diverse carpentry joints used in traditional buildings and the need to develop robust analytical assessment methods that allow to determine their current and future performance and eventual need for strengthening. The approach common in literature is to study the geometry of a specific joint, reproduce it in the laboratory as faithfully as possible and test it to determine behavior, capacity and stiffness, [21, 22]. Guidelines for their assessment are not included in EC6 and the joints are always assumed as reinforced with metallic elements. Activity in this Task Group is still at an early stage, however it is very topical for future development of research in this area and five of the STSMs carried out in the frame of the COST Action FP1101 so far are focusing on it. So far dovetail joints, mortice-tenon joints and copping joints have been studied using the component method approach. However for this method to yield robust results, it needs either calibration with advanced numerical modelling or with laboratory tests at real scale. For the modelling the use of "cohesive" surfaces has been proposed to better account for the effect of friction.

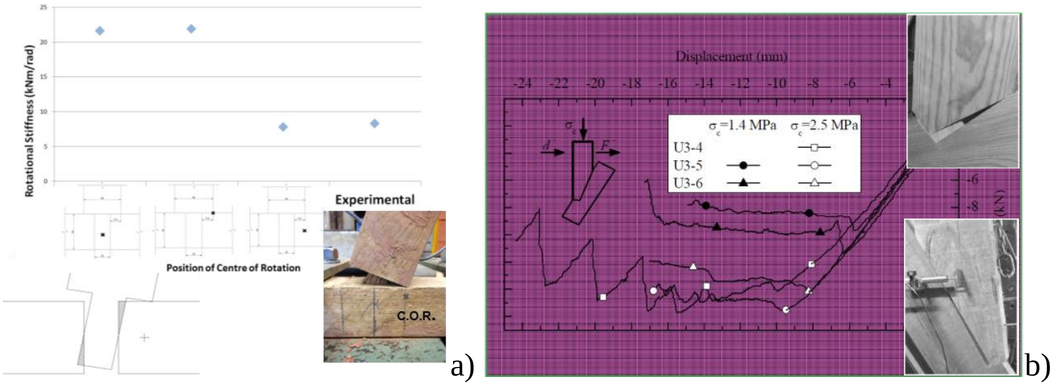


Figure 6: a) Calibration of the component method by use of test; b) testing of joints at real scale

Another typology of carpentry studied is the plain lap joint of planked arches with wrought iron nails (Figure 7) [23]. This was tested and studied in details to determine the rotational and shear stiffness of the joint. In a first approximation it is assumed that the joint is not affected by friction between the plank as the nail are pyramidal and not anchored, hence the contact between the planks is not guaranteed. The objective is to determine the semi rigid behavior of the carpentry joint and its limit of capacity and deformability. Once the stiffness and strength of the joint are characterized a nonlinear finite element numerical model of a complex structure is developed to determine its performance under seismic action and verify the need for satrengthening.

Figure 7: a) In situ plain lap joint for planked arches; b) F.e. model of a timber vaults

The immediate objectives of the WG1-TG3 for the next six months are:

- To create a repository of relevant publications
- To create a lexicon in English and original name depend on geographic location of and carpentry with drawings and proportional dimension of joints and their use in specific structures.
- To build a database, on the base of the collected literature and from on-going projects containing details on Research Institution/s; Type of carpentry joint studied;

Type of reinforcement applied, if any; Method used for joint analysis (e.g. numerical, analytical and experimental approaches); Characteristics/parameters investigated; Problems and limitations encountered.

The analysis of this material will highlight further research avenues and future strategies.

2.4 Training Schools

One of the most important outcomes of the Training School in Athens which was held in October 2013, organised by Eleftheria Tsakanika and hosted by the National Technical University of Athens, was the dissemination of knowledge and sharing of experiences among scientists of different countries (12) and from different scientific fields. The Training School was attended by architects, civil engineers, archaeologists, wood technologists and conservators either as trainees or trainers, and the objective, as the first training school of the Action, was to present all the stages of a restoration project concerning historic timber structures from visual inspection and assessment to strengthening and monitoring, and the need of a multi-disciplinary collaboration during all the stages of such project.(Figure 8) The dissemination of knowledge and interaction was expanded during the 1st and the 3d day of the TS to technicians that work on restoration projects in Greece. During the evening session (work on site) the technicians applied reinforcing methods under the directions of the trainers, participated in relevant discussions and commented the presented videos of reinforcing/repair methods used by them during the actual restoration works. (Figure 9)

Figure 8: On site assessment activity during the Training school in Athens and explanation of sizing of double scarf joints.

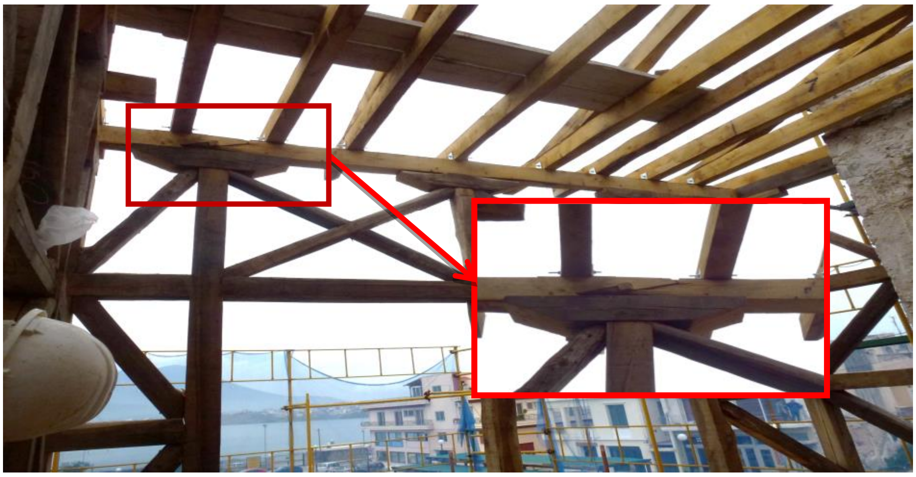


Figure 9: the same joint of Figure 8 has been carved and implemented in the structure under restoration.

Apart from the presentations by slides of several restoration projects (morning session), the participants (trainees and trainers) had the opportunity to visit an historical building under restoration and other 10 completed restoration projects (5 the 1st day, 1 the 2nd day, 2 the 3d day and 3 the 4th day), discussing and commenting on site the realized works. For the trainees additional “homework” relevant to the scientific topics and the cases presented during the TS with ECTS credits when needed was organized. The trainees were required to conduct a study-assessment of a timber structure of their choice. These reports will be published on the Action websites.

A FTP server was set as a platform to gathered information about all above instruments. Different levels of access are available depending on the type of information. For example, all participants are able to upload photos and videos taken during the Training School, as well as the work that the developed assignments set during the training. This information is available to all members of the Cost Action FP1101: the training schools sets of notes and assignments constitute a valuable reference set for young researchers, scholars and professionals in the field of the COST Action and ways of providing public access are being sought.

2.5 Short-Term Scientific Missions

The STSM are the tool of the Action where Early Stage Researchers (ESR) have the opportunity to work for a period up to 3 months with researchers in a different institutions on a specific topic. This is the most important tool of the Action , as new ideas are developed in this way and progress is made in the discipline. Both the ESRs and the hosting Institutions are not required to be previously involved in the action, but they need to submit a proposal for approval to the Action Core Group which assess whether the proposal fulfil the criteria and the Memorandum of Understanding of the Action. Below is a list of the participants and topics of the STSM carried out so far and of the ones planned. More information and a detailed presentation of the results achieved, are available on the action website [15].

1. Gerhard Fink, ETH Zurich, Switzerland, went to NTNU Trondheim, Norway, to work during 1 month on the topic *risk based analysis of partly failed or damaged timber constructions*, under the supervision of Prof. Jochen Kohler;
2. Natalie Quinn, University College London, England, went to University of Mons, Belgium, to work during 1 month on the topic *analysis and strengthening of Peruvian mortice and tenon connections*, under the supervision of Prof. Thierry Descamps;
3. Jose-Ramon Aira, Universidad Politecnica de Madrid, Spain, went to University of Mons, Belgium, to work during 2 months on the topic *analysis by FEM of stress distribution in traditional timber joints*, under the supervision of Prof. Thierry Descamps;
4. Tomasz Nowak, University of Technology, Poland, went to Chalmers University of Technology, Goteborg, Sweden, to work during 2 weeks on the topic *diagnosis of timber structures using non-destructive techniques*, under the supervision of Prof. Robert Kliger;
5. Carina Fonseca Ferreira, University College London, England, went to Universidad Politechnica de Madrid, Spain, to work during 3 weeks on the topic s*eismic assessment of historical vaulted timber structures*, under the supervision of Prof. Jose Fernandez-Cabo;
6. Alexey Vorobyev, Uppsala University, Sweden, went to University of Montpellier, France, to work during 1 month on the topic *mechanics of wood deformation at multiscale levels*, under the supervision of Prof. Olivier Arnould
7. Dr. Ivan Giongo, University of Trento, Italy, went to Auckland University New Zealand, to work during 1.5 months on *Seismic Assessment of Reinforced and Unreinforced Timber Floor Diaphragms*, under the supervision of Dr. Jason Ingham.
8. Ms Teresa Artola , Basque Country University, Spain, went to National University of Ireland, Galway, for 1 month to work on *Development of a decision support toll for timber reinforcement selection*.

3 PLANNED ACTIVITIES

The specific objectives defined by the management committee of FP1101 for 2014, and already partially fulfilled, are:

1. Promote participation from other COST countries. Turkey and Romania have now joined;
2. Conduct focused meetings for WG1-TG1 with the aim of producing 2 templates, one for inspection reports and one for vulnerability assessment of timber structures;
3. Organize a workshop for WG1, TG2 and TG3 and WG2 in connection with the PROHITECH conference on Strengthening and upgrading of historic timber structures; hold a thematic session on timber structure at the conference. Six papers were presented during this section.
4. Continue improving the database of ongoing project in all three areas;
5. Continue improving the database of publications prepared by individual WG members;
6. Publication as special issues in learned journals of the STARS for WG1-TG2, WG2 and WG3;
7. Conduct two training schools, one in the area of WG3 Monitoring and one in the area of WG2 Strengthening; a third TS will be carried out on the topic of WG1-TG3.
8. Prepare a joint meeting with FP1004 on "Highly performing timber structures: Reliability, Assessment, Monitoring and Strengthening", on Timber bridges, which will take place in Biel in September 2014 ;
9. Conduct a minimum of 10 STSM in the field of interest of the 3 working groups. Currently six have taken place so far this year.

The TG1 has two main targets to deliver for 2014: an "inspection report template" and a suite of "vulnerability assessment templates". These two outputs will determine a standard for Assessment and identification of vulnerability of existing structures, across Europe, a major deliverable of FP1101. Within TG2, the STAR has been completed and by July 2014 the online version will be published in the Action website. From the outcome of the STAR a set of recommendation for use of NDT in timber will be produced to be proposed as European standard. Also TG3 is working on the publication of the recent research advances on available analytical and experimental methods for the assessment of timber joints in existing structures, in collaboration with WG2. WG2 will also shortly publish a STAR report in the form of a e-book. A number of chapters has already been submitted and reviewed. The ongoing WG3 activities also showed that within some of the projects there is now space for STSMs offered by F. Lanata (Nantes) and M. Krause (Berlin) on monitoring data analysis (Nantes) and ultrasound investigations (Berlin). These topics will be also the focus of the Traning School in Nantes planned for June 2013.

4 CONCLUSIONS

The success of the Action is ultimately measured by the ability to produce guidelines for dissemination and harmonisation of the knowledge on assessment strengthening and monitoring of existing timber structures produced at European level and further afield.

Five STARs will be prepared. One has been published; other three are now at various stage of advancement, with the last to be completed by the end of 2014. All of these will be published in highly reputed international journals, seeking the widest distribution and high impact factor. Moreover the Volume of Proceedings of the SHATIS conference represents in itself a state of the art compilation for the 3 WGs and it is available on line.

The Training Schools were also very successful and they meet the scientific objectives of both WG1 and WG2. They have fostered some very good technical exchanges among trainees and trainers and have seen some further activities developed as a result.

Five STSM have been successfully completed. The objective is to double the number for 2014. Moreover all STSMs completed in 2013 have resulted in very important interactions among members' institutions and such interaction is continuing past the STSM period with inputs and possibility of further bi-lateral funded activities.

Many FP1101 members also participate in standardization bodies, in TCs particularly devoted to the Action's theme, such as the CEN/TC 346/WG 10 "Conservation of cultural heritage - Historic Timber Structures - Guidelines for the On Site Assessment". This will have a very important impact, allowing optimization of efforts and results, in the production and adoption of relevant standards and recommendations [22]. Some members of the WG1 are also RILEM TC 245 RTE "Reinforcement of Timber Elements in Existing Structures", thus allowing fruitful interaction with non-COST and non-EU countries and encouraging transfer and application of relevant knowledge worldwide.

5 ACKNOWLEDGMENT

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