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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.

KEYWORDS: Assessment, Strengthening, Monitoring, Research networks, Standardisation

1 INTRODUCTION

In recent years, timber in new structures has become increasingly used, both in its natural form and in engineered products, as the argument for sustainable, renewable and low CO_2 emission construction industry gains momentum and acceptance. Moreover timber has been used as structural material for centuries and its durability is demonstrated by numerous heritage structures worldwide, which properly designed and built have stood the test of time. Fundamental to the longevity of these structures is their adequate assessment and monitoring and appropriate strengthening interventions, when needed.

The last decades were marked by a widening in the range of application of timber in structures and consequently a growing importance of the assessment of these structures. The time and cost of structural assessment are justified by ensuring safety, and protecting investments and cultural heritage.

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A wide variety of methods exist to evaluate timber structures, however, their frequency and scope, the decision making approach concerning safety and the necessary interventions are far from being agreed upon. Most assessment methods used today can give qualitative information about the state of in-situ timber structures, but only few give reliable quantitative information [1,2].

Methods can be non-destructive (NDT); which are useful for the screening of potential problem areas for the qualitative assessment of structures. But a drawback of NDT is the relatively poor correlation between the measured quantity and material strength. Semi-destructive techniques (SDT) bridge the gap between NDT and fully destructive methods; they often require the extraction of samples for subsequent testing to determine stiffness and strength parameters while preserving the member's integrity. One problem of SDT is the high variability in test observations.

The need for structural reinforcement of timber buildings results from various requirements such as change of use, deterioration, exceptional damaging incidents, new regulatory requirements, or interventions to increase structural capacity. About 50% of all construction in Europe is related to existing buildings, this leads to a growing need for the maintenance and upgrading of existing buildings, not only for economical but also environmental, historical and social concerns. Over 80% of European buildings are over 50 years old; they need to be

upgraded to reflect the requirements of energy- and use-efficiency [3,4].
Recent developments related to structural reinforcement [5-10] 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 [11], which only stands as one example of a series of structural failures [12]: e.g. those of over 50 timber structures in Sweden [13].
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 [14,15], presently, the monitoring of timber structures mostly consists of regular on-site visits [16,17] that only give qualitative answers to whether a structure conforms to regulations or not.

2 COST ACTION FP1101

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 [18]. The main aim of the FP1101 COST Action is to increase the acceptance of timber in the design of new structures and its longevity in historic and existing structures by improving the robustness of methods to assess, reinforce and monitor such structures, and facilitate the dissemination and uptake of these methods. The need for assessment, reinforcement and monitoring of timber structures can arise from multiple motivations such as the expiration of the planned lifetime, materials aging, exceptional incidents, and ever more important, a change of use or of environmental conditions. 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.

3 STRUCTURE AND METHODS OF THE ACTION

The Action is aimed primarily at European economic/societal needs. An increased and more innovative use of timber as a building material based on stronger confidence will bring environmental and economic benefits since more and more durable timber structures, e.g. with projected service lives longer than 50 years, are vital in the development of a low-carbon economy. The Action is subscribed by 22 European countries and New Zealand as International partner country [19]. The objective of the Action is to increase the confidence of designers, authorities and end-users in the safe, durable and efficient use of timber and increase its acceptance and use in the design of new and in the repair of historic and existing buildings. The Action is organised in three main streams of activities which mirror the typical process followed when aiming to extend the life in service of a timber structure: assessment, reinforcement and monitoring. A working group of scientists and technologists is organised around each of these themes and a set of objectives and tasks is identified to progress and harmonise the state of knowledge through the membership of the Action and promote development of further research where gaps are identified. Three working groups (WG) have been defined: (WG1) Assessment, (WG2) Strengthening and (WG3) Monitoring.

3.1 WG1 - ASSESSMENT

Currently the WG1 Assessment has a membership of 75 organised in three task groups: TG1 Identification of Vulnerabilities, TG2 Correlation and enhancement of NDT and NDE techniques, and TG3 Methods for assessment of traditional carpentry joints. The WG1 has adopted as reference state of the art two publications recently produced by RILEM TC 215 and COST E55 [1] and [2], respectively. The major objective of TG1 is the development of a template to be used by experts to collect information about typical failures/vulnerabilities of timber structures according to the differing structural and construction types. The topic of TG2 covers an area where there has been considerable research activity in the past; however, guidance for a systematic approach to a choice of NDT techniques for timber structures is currently available neither in literature nor as a European standard. TG3 has been established with the aim of delivering a state of the art report on available analytical and experimental methods for the assessment of timber joints in existing structures, in collaboration with WG2.

3.2 WG2 - REINFORCEMENT

The WG2 on Reinforcement has 62 members and works closely with FP1004 [20] and with the RILEM TC 245 RTE Committee [21]. Two separate task groups work on bonded-in rods and self-tapping screws as means of elements and connection strengthening, while a third task

group is working on an IT-based decision support tool to guide the designer in the choice of the most suitable strengthening technique for a given structural lay-out, problem, and wood species. An important contribution of WG2 is the publication in mid-2014 of a State-of-the-art Report (STAR) on the reinforcement of timber structures.

3.3 WG3 - MONITORING

The WG3 on Monitoring has a membership of 40 and represents the most novel aspect of the Action. Although applications of monitoring techniques are relatively common in timber engineering, methods and approaches are mostly borrowed from the expertise in use with other materials. This means that techniques are often adapted on a need basis with relatively modest consistency and coherence. Currently however, in Europe, there is an increasing number of institutions actively researching this topic although output have not yet consolidated in a shared state of the art. Hence the STAR that will be prepared by WG3 has the critical role of setting a common basis for the timber monitoring international research community.

4 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.
The Action has co-organised in collaboration with Trento University an international conference on Structural Health Assessment of Timber Structures (SHATIS 2013), and three workshops for each of the working groups (Wroclaw 2012, Telc 2013, Trento 2013).
Short Term Scientific Missions (STSM) and Training Schools (TS) are aimed at knowledge transfer and collaboration between senior and younger researcher across European and international institutions. Two training schools with a participation of more than 25 trainees and 7 international trainers have been organised in Athens and Mons on different themes identified as strategic area of research by the working groups.
A FTP server was set as a platform to gather information about all of the 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. In the beginning all shared documents will remain "private", then a part or all of the above collected material will be open to all members of the Cost Action FP1101 and external website visitors. All the gathered information can be of major importance for many young researchers, scholars and professionals in the field of the COST Action.

4.1 CONFERENCES AND WORKSHOPS

At the meeting in Trento, the TG1 leader Eleftheria Tsakanika (School of Architecture NTUA, Athens, Greece) presented a first draft proposal of the template. It has been proposed to use the template 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. Other possible forms could be developed for different timber structural 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, will be included in the planned development of “vulnerability assessment templates”.
Following the first workshop in Telc on techniques for nondestructive testing and identification of mechanical characteristics of timber elements, which was attended by more than 40 members of FP1101, with demonstrations and presentations, the TG2 leader José Saporiti Machado (LNEC, Lisboa, Portugal) proposed in the meeting in Trento a table of contents for the State of the art report on “Combination of NDT/SDT for the assessment of timber structures on site”.
This STAR will be substantially different from the RILEM publication, which focuses on instruments and methods. Indeed the focus of the TG2 STAR will be on the objective of the investigation (i.e. estimation of reference material properties, identification of damages and decay, etc.). Hence an important section of the report will be dedicated to statistical methods for data processing and analysis. The report will be completed by a section on selected Case studies, where application and limitation of use of the discussed methodologies are reported. Several contributions are co-authored by members of FP1101, who will submit joint contributions by thematic topics.
The STAR will be published first in the form of a book and in a special issue of an international journal.
While the activity of TG3 is still at an early stage, many of the STSMs carried out in the frame of the COST Action FP1101 so far are focusing on this topic. In total, three presentations were given at the TG3 meeting in Trento, the first two as results of successful STSMs and the third one by one of the early stage researchers.
The discussion following the presentations, focuses on the importance of considering local phenomena (e.g. friction, position and extension of contact areas, etc.) when modelling specific types of connections.
WG2 introduced a novel form of networking through the delivery of practical workshops followed by research papers presentation and discussion. At the workshop in

Telc, Czech Republic, a practical on "Reinforcement of elements and connections" presented by Rotafix Technical Director Dave Smedley, was followed by theoretical presentations made by FP1101 members. In Trento, Italy, a practical session was organised by the Materials and Structural Testing Laboratory, University of Trento, on "Application of self-tapping screws for the reinforcement of timber structural elements" and delivered by Albino Angeli, Rothoblaas. In addition, Prof. Maurizio Piazza presented the facilities of the Laboratory. Detailed information was provided on the design of the test rig for racking tests and a demonstration of vibration testing of a timber floor was given. This was followed by four presentations by early stage researchers (ESRs).

A second innovative networking activity has been the joint workshop of WG1 and WG2 in Trento on the development of a Decision Support Tool for the Selection of Reinforcement. The WG2 leader, Annette Harte, and Teresa Artola Guijarro, PhD student from Bilbao, Spain, have proposed a framework for an IT-based decision support tool of which aims and objectives where discussed at length during this workshop. The WG2 leader highlighted the need of collaboration between WG1 and WG2 for this task, since a decision tool has to start from the assessment of the actual condition of a structure, in order to support selection of possible reinforcements. It was agreed that the best way to collaborate is to include outputs of the WG1-Task group 1 into the development of the IT-based assessment tool. To ensure continuity Teresa Artola will participate to WG1-TG1 activities, and will contribute to the development of a specific report template on the case studies selected in her research (wooden churches). Furthermore, Jiří Kunecký (ITAM, CZ) reported of an on-going research project at ITAM on an IT-database on building failures, which could be adapted for the specific needs of TG1 tasks. Further work on harmonising these tools is currently undertaken.

WG3 also organised a Workshop in Trento. The workshop presentations showed the ongoing work in the projects the members of WG3 presented. Several of the topics were already addressed during the workshop in Wroclaw in 2012. The increase of experience and knowledge regarding the different aspects of monitoring is clearly visible. Each presentation was intensively discussed.

4.2 TRAINING SCHOOLS

One of the most important outcomes of the Training School in 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, since the aim of this TS was to present all the stages of a restoration project concerning historic timber structures (overall approach) and the need of a multi-disciplinary collaboration during all the stages of such project. The dissemination of knowledge and interaction was expanded during the first and the third 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 on the presented videos of reinforcing/repair methods used by them during the actual restoration works.

Apart from the presentations by slides of several restoration projects (morning session), the participants (trainees and trainers) had the opportunity to visit one historical building currently under restoration and ten, which had already been restored (5 the 1st day, 1 the 2nd day, 2 the 3d day and 3 the 4th day), to discuss and comment 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 is organized. All trainees had to deliver it within 3 months. In the training school on assessment and reinforcement of timber elements held in Mons, Belgium, the intensive courses, delivered over five days during the second week of December 2013, comprised lectures, exercises and laboratory demonstrations. All lectures and other presentations were delivered in English (Figure 1).

a) Overview of the class room

b) Example of NDT made on-site

Figure 1: *Photos taken during the Mons training school*

For PhD students, additional "homework" with 7.5 ECTS credits was proposed. This work was optional and was carried out after the training school by groups of two

students from different institutions. It consisted of preparing a design note about the assessment of one existing timber structure (new or old) in their home region

4.3 SHORT-TERM SCIENTIFIC MISSIONS

A total of six STSMs took place in 2013 all by ESRs:

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.

5 PLANNED ACTIVITIES

The specific objectives defined by the management committee of FP1101 for 2014 are:

1. Promote participation from other COST countries. Romania has been approached;
2. Conduct focused Task Group meetings for each of the WG1 task groups 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 PROHITEC conference on Strengthening and upgrading of historic timber structures; hold a thematic session on timber structure at the conference.
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. Review and publish 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;
8. Prepare a joint conference with FP1004 on “Timber Bridges”;
9. Conduct a minimum of 10 STSMs in the field of interest of the 3 working groups.

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 plan is to have a final draft of the STAR by March 2014. 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 publish the STAR on the Reinforcement of Timber Structures in hard and soft copy format. In addition, it is proposed to have this work published in a Journal Special Issue. 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).

6 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.

Five STARs will be prepared. One has been published; other three are due at various stage of advancement, while the last will 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.

Six STSM have been successfully completed in 2013. 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. 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.

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REFERENCES

[1] Kasal B and Tannert T (Eds) (2011) In-situ assessment of timber: RILEM State-of-the-Art Report 7. Springer, ISBN 978-94-007-0559-3.

[2] Dietsch P and Köhler J (Eds) (2010) Assessment of Timber Structures: Report COST Action E55. " Shaker, ISBN 978-3-8322-9513-4.

[3] Itard L, Meijer F, Evert V and Hoiting H (2008) Building Renovation and Modernisation in Europe: State of the art review. OTB Research Institute for Housing, Delft, The Netherlands.

[4] Housing Statistics in the European Union 2004 (2005) Boverket, National Board of Housing, Building and Planning, Sweden ISBN 91-7147-865-5.

[5] Dietsch P, Mestek P, Merk M, Winter S (2008) Structural safety and rehabilitation of connections in wide-span timber structures - two exemplary truss systems. Proc. 10th World Conference on Timber Engineering. Miyazaki, Japan.

[6] Kasal B, Heiduschke A (2010) The Use of High-strength Composites in the Reinforcement of Timber. Advanced Materials Research, 133-134:941-946.

[7] Haller P (2007) Concepts for textile reinforcements for timber structures. Materials and Structures 40(1):107-118.

[8] Blaß HJ, Bejtka I (2005) Self-tapping screws as reinforcements in connections with dowel-type fasteners. Proc. CIB-W18 Meeting, Karlsruhe, Germany. Paper 38-7-4.

[9] Bertolini Cestari C, Crivellaro A, Marciniak M, Marzi T, Socha M (2010) Nanostructured materials for durability and restoration of wooden surfaces in architecture and civil engineering. Proc. 11th World Conference on Timber Engineering, Riva, Italy.

[10] Bertolini Cestari C, Marzi T, Invernizzi S, Tulliani JM (2008) Nanotechnologies applied to the restoration and maintenance of wooden built heritage, Proc. 6th International Conference on Structural Analysis of Historical Construction, Bath, United Kingdom.

[11] Winter S, Kreuzinger H (2008) The Bad Reichenhall ice-arena collapse and the necessary consequences for wide span timber structures. Proc. 10th World Conference on Timber Engineering. Miyazaki, Japan.

[12] Frese M, Blaß HJ (2011) Statistics of damages to timber structures in Germany. Engineering Structures; doi:10.1016/j.engstruct.2011.02.030.

[13] Frühwald E, Serrano E, Toratti T, Emilsson A, Thelandersson S (2007) Design of safe timber structures – How can we learn from structural failures in concrete, steel and timber? Report TVBK-3053. Lund University, Sweden.

[14] Tannert T, Berger R, Vogel M, Liebhold P. (2011) Remote moisture monitoring of timber bridges: a case study. Proc. 5th Int. Conf. on Structural Health Monitoring of Intelligent Infrastructure (SHMII-5) 11-15 December 2011, Cancún, México.

[15] Henke K, Pawlowski R (2012). Continuous deflection monitoring of large-span timber structures on the basis of digital image processing. Research Report. Chair for Timber Structures and Building Construction (TU München) and Hochschule Karlsruhe, Germany.

[16] Blaß HJ, Brüninghoff H, Kreuzinger H, Radovic B, Winter S (2006) Guideline for a first evaluation of large-span timber structures. Council for Timber Technology. Wuppertal, Germany.

[17] SIA 269/5 (2011) Existing Structures–Timber Structures. Swiss Society of Engineers and Architects SIA. Zurich, Switzerland.

[18] www.costfp1101.eu

[19] www.cost.eu/domains_actions/fps/Actions/FP1101

[20] www.rilem.org/gene/main.php?base=8750&gp_id=288

[21] http://costfp1004.holz.wzw.tum.de