DEVELOPMENT OF A DECISION SUPPORT TOOL FOR TIMBER REINFORCEMENT SELECTION

HOST INSTITUTION: NATIONAL UNIVERSITY OF IRELAND, GALWAY

FINAL REPORT OF A SHORT TERM SCIENTIFIC MISSION

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1. PURPOSE OF THE SHORT TERM SCIENTIFIC MISSION (STSM)

In our European context, the destruction of wooden heritage is occurring at an increasing pace all over the Carpathian Mountains and as it stands, there are no strategies or policies to slow the phenomenon.

So their present condition is not very encouraging, often ignored by the village communities and deemed as minor patrimony by governmental authorities; even of those legally protected, only a few are preserved in their initial condition.

In connection to that, a targeted action to modernize and improve the knowledge-base of the timber restoration and maintenance sector is particularly appealing which is even mentioned as a relevant point in the Memorandum of Understanding of COST Action FP1101: "Developing computational concepts that allow for safe and reliable design of reinforcing measures".

Important and widespread examples of structural systems are the traditional roofs of the buildings, very illustrative of the rural trends in European timber technology.

In historical timber roofs numerous structural systems, materials and details exist, that requires the designer (architect, engineer...) to be careful in the detailing and choice of the appropriate system of reinforcement. The choice demands knowledge and expertise in the restoring process which sometimes is insufficient and unstructured, making it difficult to find an optimal solution. Research related to structural timber reinforcements commonly results in new methods, new materials or innovative methods of application. The findings of the research are generally disseminated in the form of publications (scientific books, journal papers or articles), seminars or conference proceedings. Therefore, although this work is of great value, there is an elongated timeline to utilisation due to traditional dissemination being employed.

The mentioned aspects show us that the designer has to be supported in the decision making. Basic relationships for construction parts and a sufficient number of design possibilities have to be laid down in a suitable database. Knowledge based systems have to assist the user in all planning tasks with the objective to improve and facilitate the complex design of reinforcement for timber roofs. As a result, errors are minimized and time and cost can be reduced.

The purpose of my STMS at the College of Engineering and Informatics of the National University of Ireland in Galway is working on preliminary studies to develop a decision support IT tool for choosing an appropriate reinforcement method with consideration of cultural heritage aspects.

The NUI has provided the collaboration of a 2nd year MSc student in IT with a degree in Architectural Technology, and together we processed all the information and decide the best way to organize all the data.

2. DESCRIPTION OF THE WORK CARRIED OUT DURING THE STSM

During my visit the work carried out at the NUI was divided in 2 parts.

2.1. REVIEW OF PREVIOUS METHODOLOGIES

In the months prior to the STMS, work had been carried out collecting data published and known on this topic. This is listed in the Bibliography. Also during the STSM, this work has been reviewed to ensure that selected criteria are reasonable and acceptable.

At the *Arsenale* in Venice (Menichelli 2010) a model was developed for the preservation, diagnosis, and description of the timber trusses.
A range of possible interventions was defined for the insertion of prosthesis, identifying 8 types of solutions depending on the extent of the degradation and the structural behavior of the timber element. The aim was to reduce the loss of original material and not to change its structural behaviour.
The system provides a tab for each truss in a 4 different templates to follow the development of the conservation as shown in Fig.1. These are: Truss analysis, Material consistency analysis, Intervention proposed and Map of the performed tasks.

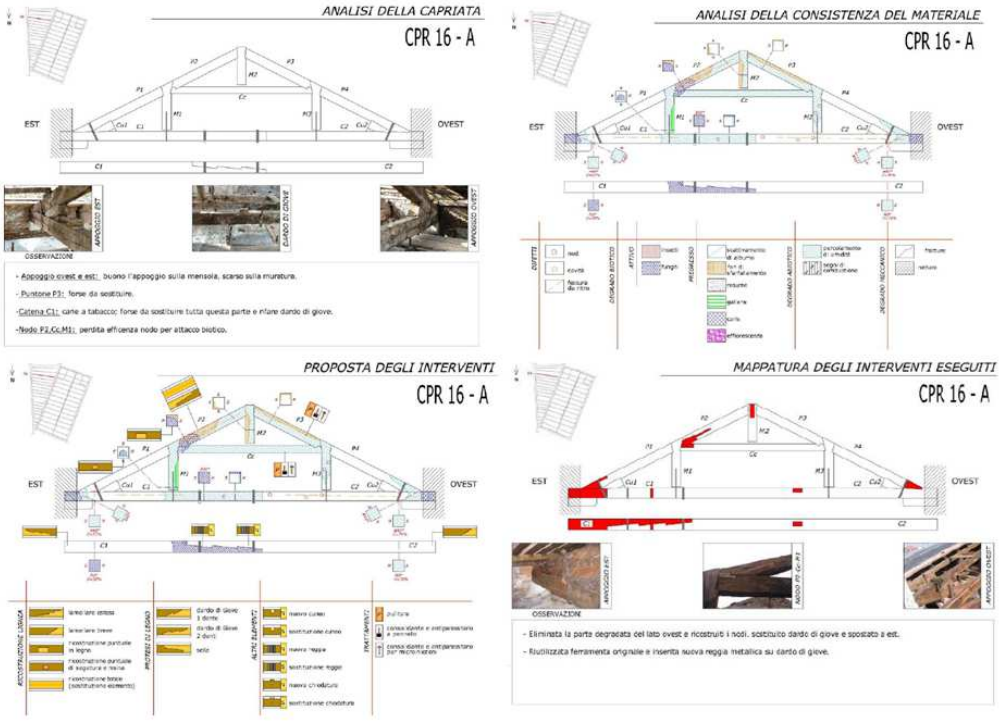


Fig. 1 Arsenale Venezia, [Menichelli, 2010]

This work proves the importance of the systematization and individualization of each truss by selecting the degradation members or nodes.

Another good example is the NIKER Catalogue, a structured database that links earthquake induced failure mechanisms, construction typologies and materials, interventions and assessment techniques. This aims at knowledge-based optimization of interventions and definition of main design parameters and requirements for materials and intervention techniques. More info: http://www.niker.eu/

The relationship between the different typologies of timber roof structures (non thrusting and thrusting structures) and the failure mechanisms (inadequate bending strength and stiffness, inadequate in-plane stiffness, slipping at supports, material degradation, out-of-plane instability, joints failure) is shown.

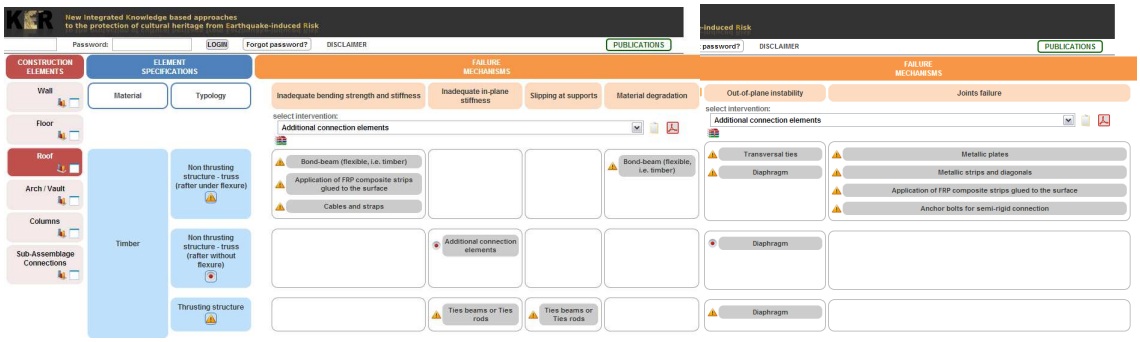


Fig. 2 Niker Catalogue [niker.dicea.unipd.it]

This work is focused on seismic performance but presents a way of linking solutions with the different failure origins.

2.2. DECISION SUPPORT TOOL: INTERFACE DESIGN AND IMPLEMENTATION

Decision making is a common process in everyday human life, and in many cases it´s a very difficult one as it includes conflict of interest, unknown aspects, elements difficult to evaluate, etc... This leads to a situation where there is not just one solution that is better in all the aspects, but a compromise, which takes into account different views of different stakeholders.

Decision-making can be regarded as the cognitive process resulting in the selection of an action among several alternative possibilities. A Decision Support Tool (DST) helps individuals and organizations with their decision-making processes, typically resulting in ranking, sorting or choosing from among alternatives.

Multi-Criteria Decision Analysis (MCDA) is a set of methodologies that help the decision maker during the decision-making process. MCDA methods are not intended to replace the decision maker, but rather help them think in a systematic and orderly manner on complex problems in order to improve the quality of the final decisions, allowing the incorporation of different aspects.

Decision making about proposals for future action should normally follow the sequence below. The following process had been applied to the development of our project.

• Identifying objectives: in our case reinforcement method for timber trusses

• Identifying options for achieving the objectives: different repair methods

• Identifying the criteria to be used to compare the options: architectural best (following the ICOMOS recommendations), economical cost and the environmentally friendly best solution.

• Analysis of the options

• Making choices

• Feedback: Good decision making requires a continuous reassessment of choices made in the past. Individual decision makers may learn from their own mistakes, but it is important that lessons be learned in a more formal and systematic way, and communicated to others, so that they can inform future decisions.

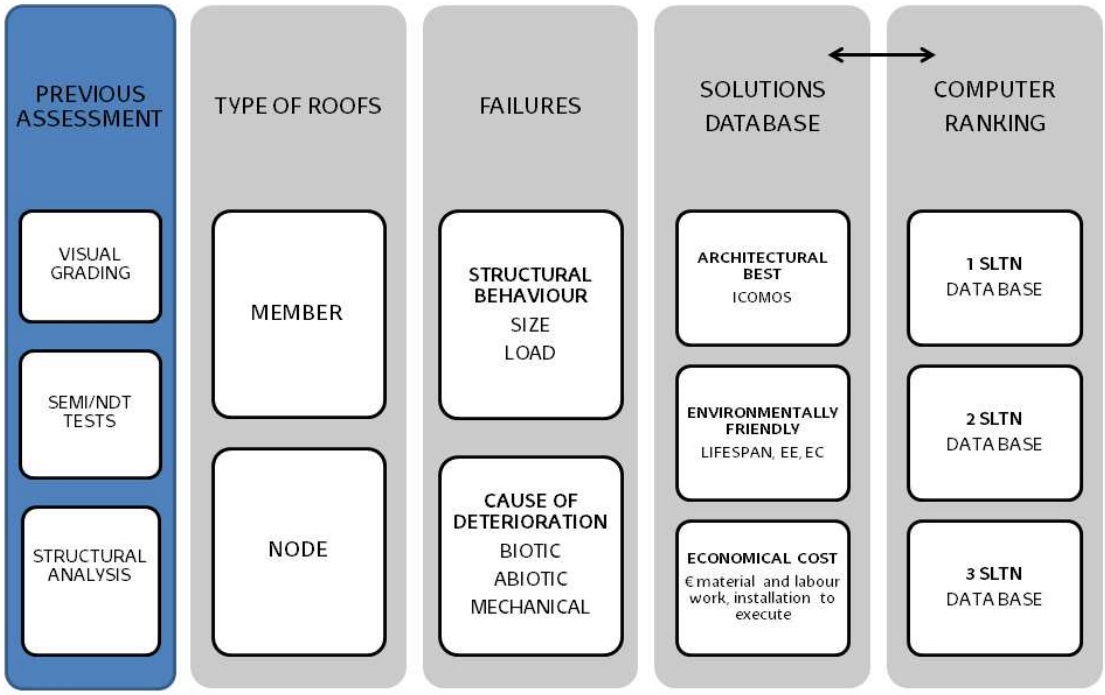


Fig. 3 General diagram

The diagram above shows a general diagram of the methodology.

It is important to highlight that we will obtain data from the previous structural assessment through 3 mechanisms: Visual grading, Non or Semi destructive tests and the Structural analysis.

Then we will start using our mobile application which interface allocates all the data: *TimberSave*. The interface isclear and simple to use so the different parameters can be filled by different users.

First of all is necessary to identify the type of roof we are going to reinforce (Monopitch, Gable or Hipped roof) where a gallery of different images will help the user to recognize the structure. After that, we will select the different causes of deterioration that have been classified into 3 groups: Biotic (Active or Passive, Insect or fungi), Abiotic (fire, natural hazard) and Structural/Mechanical Failures (members, connections, units, systems, including wood defects). Next we enter the information on the element or node, its location, structural purpose (tension, compression, bending) span, grading and percentage of the damage. We will also fill in the temperature and humidity of the environment and its heritage values.

Finally the solutions will be displayed according the 3 established criteria[1]: Architectural Best, Economic Best and Carbon Footprint Best Solutions which the user can select and visualize.

Architectural Best will include the ICOMOS general recommendations such as follow traditional means, be reversible, not prejudice or impede future preservation work and not hinder the possibility of later access. We should not forget that they are historical structures.

Economical cost and carbon footprint (environmental legislation is increasing in all the European countries) will be directly related to the quantity of necessary material for the chosen solution and the percentage of damage.

For the selection of the optimum reinforcement method a database (knowledge base) with interventions solutions linking to different damages must be created and will include information such as limits and advantages, specific design, possible restrictions, references, maintenance and fire performance observations.

Once the database is set up with the most usual reinforcement solutions among the experts, we will work on the ranking system. By comparing the value units of the different alternatives, the app will show you an objective choice based on the best ranking solutions but the preferences of decision makers, regarding the proposed indicators, must be known. Our 3 rating levels must turn into a comprehensive rating index by introducing weighted parameters. As an example, the assigned weight (from 1 to 10) will indicate the relative significance of a historic building if we gave a high rate on the architectural criteria and that can be also used with other purposes, like for conservation and intervention policies development.

2.3. CONCLUSIONS

The present DST describes only one way of approaching towards the choice of the best reinforcement solution to historical timber roofs, which is intended for use by experts carrying out strengthening works.

It can have at least three major benefits: a) a uniform catalogue of solutions that will be available and can be easily updated, b) experts will be more aware on the chosen factors in rating solutions for the client, c) major deteriorations in timber roofs will be identified and recorded.

It is evident that 3 weeks of work are not enough and the tool needs further development in future studies about the solutions database and the way of rating. Also the collaboration with the WG1-TG1 and their template for Assessment of Damages in Timber Structures will bring new questions on the table.

[1] Following WG1-TG1 Meeting in London (19/02/2014), it was agreed to include a 4th item in future work, the Structural Best criteria.

3. DESCRIPTION OF THE MAIN RESULTS OBTAINED

After the work described above, here are the images that shows, step by step, the mobile app process that has been designed together with Richard McCormack.

Step 1
An Option is selected from the dropdown 'Subcategories' List.

Subcategory R1a: '**Purlin**' was selected here.

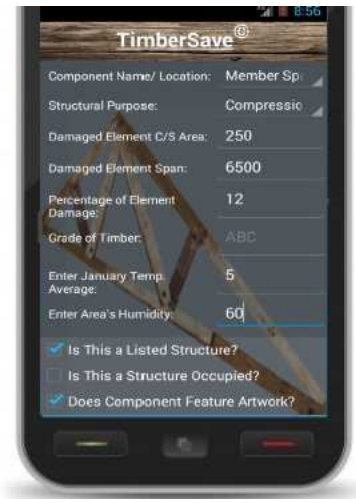
Step 2
All Issues applicable to the category '**R**' (Denotes **R**oof elements) are loaded, under 3 tabs: **R1.1, R1.2, R1.3**. These tabs denote the areas of 'Biotic', Abiotic, and 'Structural' damage issues

Issue R1.1: '**Passive Insect Infestation**' was selected here.

Step 3
Next we will collect information on the component of the element (currently just '**R**oof types') which is being assessed.

The first 2 fields are drop-downs, which establish the location of the damage (Joint, End or Span) & the structural purpose of that component (Tension, Compression or Bending).

In this case we have selected '**Member End**', which is in '**Tension**', which, along with the issue (**1.1**), will refine the Database matching results returned.



Step 4
We fill in the remainder of the of the fields, which will affect the costing values in **Step 6**...

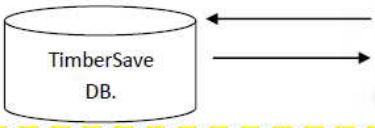
Here we have defined a **Compression** member with a volume of **250mm²x6500mm**, and previous **Insect Damage** (from **Issue 1.1** selected in **Step 2**) along it's **Span**, of **12%**.

The area in which this roof is located has a January (coldest month in Europe) average temperature of 5°C, and humidity of **60%**.

Additionally, this is a **Listed** Structure, with an **Artistic Feature** on the component being assessed.

Step 5
The component Issue selected (**1.1... 'Passive Insect Damage'**), is damaged on the **'Span'** of a **'Compression'** member. Hence, our results returned are limited to Solutions that match these criteria, in 3 respective fields (parsed string passed to query).

The current 'dummy' data, populating the Solutions table, yields just 2 such matches (**R1**, **R2**), which are displayed in tabular form below...



SolnID	Solution Name	Solution Descript.	Soln. Image Name	Issues Applicable	Damage Locat. Applicable	Component Types Applicable
1	SolnR1	This is Soln R1 Text	AddressR1	R1.1, R1.3, R2.3	Joint, Member End, Member Span	Compression, Tension
4	SolnR4	This is Soln R4 Text	AddressR4	R1.1	Member Span	Compression

Step 6

This will be the costing of these query results, will subsequently be ranked by an algorithm under each of 3 criteria: Architectural Best, Economic Best and Carbon Footprint Best Solutions.

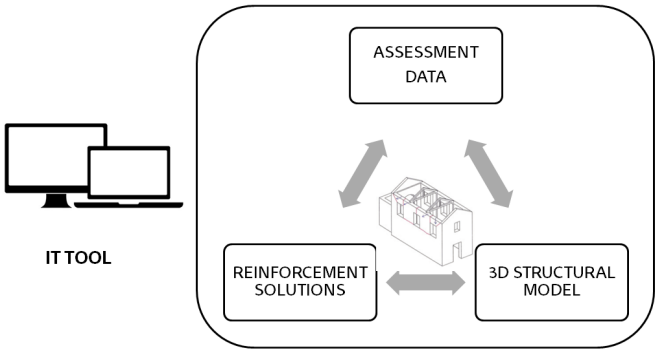
The cumulative best ranking solution will be the first in the overall list of recommended solutions, and so on... The 3 field's weighting will be adjustable (likely with the use of a slider, to give its weight out of 0-1).

→ Further research will be taken on the data base and the ranking methodology.

Step 7
Solution clicked upon currently can store the title, images, and text loaded from the Solutions Database Table.

4. FUTURE COLLABORATION WITH HOST INSTITUTION

Future cooperation between the NUI, Galway, and me would focus on a future European IT tool development that can link assessment and timber reinforcement selection to further research from the work that has been doing within the frame of WG1 and WG2 of Cost Action FP1101 "Assessment, Reinforcement and Monitoring of Timber Structures". As the development of a full tool is a significant amount of work and outside the scope of the COST Action; my intention after demonstrate the possibilities of such a tool, is to put together a consortium from the members of the Action to prepare a H2020 proposal. In this tool, automatic links will be developed with the assessment database and a structural analysis modeller that will allow for the assessment of the influence of different reinforcement strategies on the structural response.



5. PROJECTED PUBLICATIONS RESULTING FROM THE STSM

The results from this work will be presented in a scientific paper during the "Workshop on Strengthening of historic timber structures" that will be held in Antalya, Turkey, 5-6th May 2014 in advance of the PROHITECH14 Conference.

6. ACKNOWLEDGEMENTS

Firstly, I would like to thank the COST Action FP1101 organization members which contribute to improve the work of early stage researchers. I would also like to express my gratitude to Dr. Annette Harte for all her help and guidance. I would also like to thank Richard McCormack, who made the *TimberSave* app possible with his coding and providing me support during these three weeks.Finally, I would like to thank the friends and colleagues that I met, for making my winter stay in Galway much more pleasurable.

ANNEX: QUESTIONNAIRE

In order to evaluate each solution under each criteria we need the Cost Action Expert Panel evaluation. An online survey has been submitted:

https://docs.google.com/forms/d/1sd5mM1mmRcjkDzxuAHjqn7oPfaYcKL-DI1SKrvTxNCY/viewform

DECISION SUPPORT TOOL (DST) FOR HISTORICAL TIMBER ROOF REINFORCEMENT QUESTIONNAIRE

We are asking for your collaboration with your Historical timber roof reinforcement previous experiences in terms of developing the decision criteria for this tool.

Country

From which institution/company are you coming from?

Surname and name

E-mail

ARCHITECTURAL BEST REINFORCEMENT SOLUTIONS

Rate the importance of the ICOMOS recommendations* to the different reinforcement solutions on a scale of 1-10 *Follow traditional means, be reversible, not prejudice or impede future preservation work, not hinder possibility of later access

1) Prosthesis: new timber + FRP/steel bars or plates + epoxy

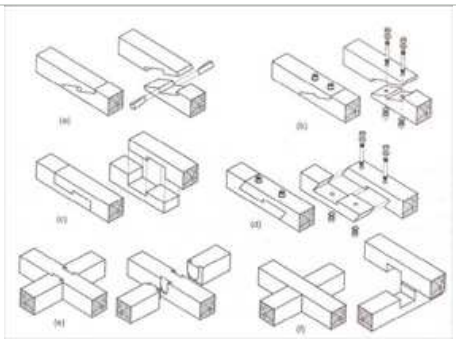
	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

2) Prosthesis: new timber + dry fixing

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

3) Prosthesis: new timber with traditional joint (i.e. Jupiter´s arrow)

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High



4) Prosthesis: new timber + Hot steel strapping (min 3 turns) + nails

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

5) Lateral timber or plywood planks in both sides* + dry fixing (i.e. stainless steel threaded rods or self tapping screws)

*Decay remove or not

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

6) Corbel in timber or steel + fixing element

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

7) Introduction of steel cables

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

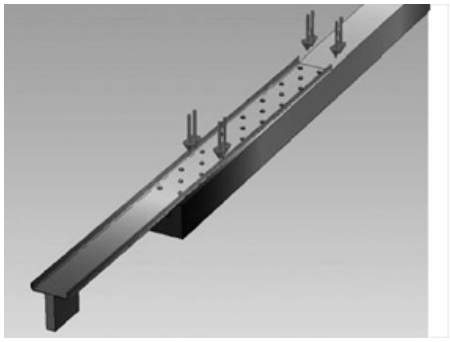
8) Connections reinforcement by external steel plates

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

9) Steel/FRP profiles with a plate* + dry fixing

*Only access from above the member

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High



ECONOMICAL COST BEST REINFORCEMENT SOLUTIONS

Rate the importance of the economic cost* to the different reinforcement solutions on a scale of 1-10
*Solutions that use less expensive materials or require lower installation cost to execute them

1) Prosthesis: new timber + FRP/steel bars or plates + epoxy

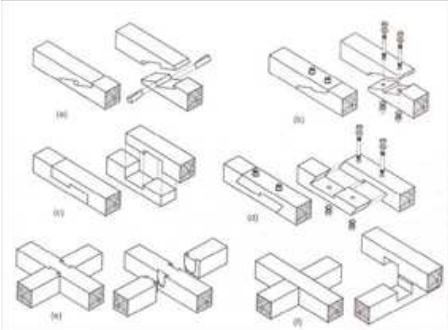
	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

2) Prosthesis: new timber + dry fixing

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

3) Prosthesis: new timber with traditional joint (i.e. Jupiter´s arrow)

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High



4) Prosthesis: new timber + Hot steel strapping (min 3 turns) + nails

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

5) Lateral timber or plywood planks in both sides* + dry fixing (i.e. stainless steel threaded rods or self-tapping screws)

*Decay remove or not

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

6) Corbel in timber or steel + fixing element

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

7) Introduction of steel cables

	1	2	3	4	5	6	7	8	9	10	
Low	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High

8) Connections reinforcement by external steel plates

1	2	3	4	5	6	7	8	9	10

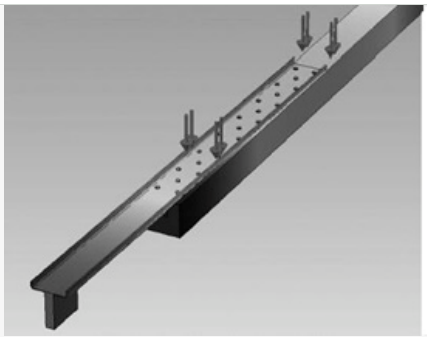
Low ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ High

9) Steel/FRP profiles with a plate* + dry fixing

*Only access from above the member

1 2 3 4 5 6 7 8 9 10

Low ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ High



ADDITIONAL SOLUTIONS

If you can think of any other solution, please fill the box above with its description, diagram or a paper reference

BIBLIOGRAPHY

AGUADO, A. and MANGA, R. & ORMAZÁBAL, G., 2006. *Los aspectos conceptuales del proyecto MIVES La medida de la sostenibilidad en edificación industrial. Modelo integrado de Valor en Edificios Sostenibles (MIVES).* LABEIN. UPV-EHU UPC.

ARRIAGA, F., PERAZA, F., ESTEBAN, M., BOBADILLA, I. and GARCÍA, F., 2002. *Intervención en estructuras de madera.* Madrid: AITIM.

BASTERRA, L.A., RAMÓN, G., BARRANCO, I., L., G., ACUÑA, L., RELEA, E. and CASADO, M., 2005. Avance de propuesta metodológica para el diagnóstico y análisis de estructuras de madera históricas, *Actas del IVº Congreso Nacional de Historia de la construcción*, 27-29 Enero 2005 2005, Santiago Huerta, pp. 121-131.

CACCIOTTI, R., VALACH, J., KUNES, P., CERNANSKY, M. and BLASKO, M. & KREMEN, P., MONUMENT DAMAGE INFORMATION SYSTEM (MONDIS): AN ONTOLOGICAL APPROACH TO CULTURAL HERITAGE DOCUMENTATION, *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2-6 September 2013.

CRUZ, H., YEOMANS, D., TSAKANIKA, E., MACCHIONI, N., JORISSEN, A., TOUZA, M. and MANNUCCI, M. & LOURENÇO, P.B, 2013. Guidelines for the On-Site Assessment of Historic Timber Structures. *International Journal of Architectural Heritage: Conservation, Analysis, and Restoration.*

D'AYALA, D.F., COPPING, A.G. and WANG, H., 2006. A conceptual model for Multihazard assessment of the vulnerability of historic buildings. LOURENCO, P. B., ROCA, P., MODENA, C. AND AGRAWAL, S., ed. In: *Structural Analysis of Historical Constructions : Possibilities of Numerical and Experimental Techniques. Proceedings of the Fifth International Conference* 2006, MacMillan India, pp. 121-140.

DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT, 28 January, 2009-last update, Multi-criteria analysis: a manual [Homepage of Communities and Local Government Publications], [Online]. Available: https://www.gov.uk/government/publications/multi-criteria-analysis-manual-for-making-government-policy [20 January, 2014].

FIGUEIRA, J., GRECO, S. and EHRGOTT, M., EDS, 2005. *Multiple criteria decision analysis: State of the art surveys.* International Series in Operations Research and Management Science. New York: Springer.

GAZTELU, L., 1899. *Pequeña Enciclopedia Práctica de Construcción publicada bajo la dirección de L.-A. Barrè. Nº4 Carpinteria de Armar. Traducido y anotado por D. Luis Gaztelu.* Madrid: Librería editorial de Bailly- Bailliere e hijos.

HALLER, P. and MENZEL, R., 1998. Computer Based Routine Design for Timber Structures, *WORLD CONFERENCE ON TIMBER ENGINEERING (5th WORLD CONF ON TIMBERENGINEERING)* 1998, pp. 486-493.

ILHARCO, T., PAUPÉRIO, E., GUEDES, J., COSTA, A., 2010. Sustainable interventions: Rehabilitation of old timber structures with traditional materials, *SB10mad - Sustainable building conference. Madrid, Spain.*

MENENDEZ J, HAIRSTANS R, LEITCH K, TURNBULL D, 2012. A Structural Engineering Platform for Timber Modern Methods of Construction, *International Conference on Innovation in Architecture, Engineering and Construction*, 14-18 August 2012 2012.

MENICHELLI, C., 2010. Le structture lignee dell´Arsenale di Venezia. Studi e restauri. *ATTI E RASSEGNA TECNICA DELLA SOCIETÀ DEGLI INGEGNERI E DEGLI ARCHITETTI IN TORINO,* 1-2, pp. 164.

NIKER CATALOGUE,10 March 2014 - last update, [Online]. Available: https://niker.dicea.unipd.it/

NUERE, E., 2007. Madera, en restauración y rehabilitación. *Informes de la construcción,* 59(506), pp. 123-130.

NUERE, E., 1998. Construir con madera. *Informes de la construcción,* 49(453), pp. 5-10.

PINTO, L., 2009. *Master´s Thesis: Inventory of repair and strengthening methods timber*, Universitat Politècnica de Catalunya.

SZABÓ, B., 2006. Restoration of Historic Roof Structures on Common Rafters and Tie-Beams with Collars, *Structural Analysis of Historical Constructions* 2006, P.B. Lourenço, P. Roca, C. Modena, S. Agrawal.

TAMPONE, G., 2001. Acquaintance of Ancient Timber Structures, *3rd Seminar on Structural Analysis of Historic Constructions* 2001, Santiago Huerta, Guimares, University of Minho.

TAMPONE, G., 1996. *Il restauro delle structture di legno*. Milano: Hoepli.

TAMPONE, G., Mechanical Failures of the Timber Structural Systems, *ICOMOS IWC - XVI International Symposium*, 11-16 November 2007.

VIÑOLAS, B., CORTÉS, F., MARQUES, A., JOSA, A. and AGUADO, A., 2009. MIVES: modelo integrado de valor para evaluaciones de sostenibilidad - ICSMM 2009, CIMNE, ed. In: *II Congrés Internacional de Mesura i Modelització de la Sostenibilitat*, 2009 2009.

YEOMANS, D., 2003. *The Repair of Historic Timber Structures*. London: Thomas Telford.