A COMPLEX ASSESSMENT METHODOLOGY FOR HISTORIC ROOF STRUCTURES

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Timber structures are a complex research topic, offering research opportunities in a wide array of domains, reaching from heritage timber structures to contemporary ones.

However, existing/heritage timber structures, bring forward a series of challenges. The complexity of this topic arises from the fact that their structural behaviour is also strongly connected to their state of conservation, the type of the traditionally crafted joints used and their link to other structural parts made of different materials.

Considering this, an extensive research was performed on roof structures from Timisoara, a city from the western part of Romania. The study highlights that besides understanding their structural behaviour, there are a series of factors, which influenced the shape of the roof and the used structural typology and that the aesthetic features and the relation with the surrounding urban area has to also be taken into consideration. Noteworthy is also to consider environmental factors which can affect their state of conservation and the link to the building and acknowledge how these structures can influence the behaviour of the buildings during seismic events. Only after such a comprehensive analysis, the roof structure can be structurally evaluated and decisions and strengthening measures, if necessary, taken.

Therefore, by respecting the ICOMOS/ISCARSAH principles which are encouraging a multidisciplinary assessment of heritage structures, a comprehensive assessment methodology suitable for historic timber roof structures was developed, which can be used to determine their value and vulnerability and be used as a decision-making tool for the planning and hierarchisation of future interventions.

In order to respond to the main objective of the thesis, it was organised in 6 chapters, considering its main objectives and approaching historic timber roof structures from two points of view which are later on interlinked at the end of the thesis. The study can, therefore, be divided into three main parts:

1. The first part is connected to an analysis of existing assessment methodologies suitable for historic timber structures meant to highlight the common approached topics, the main differences between them but also all the features which are not taken into consideration during the first phases of the assessment.
2. The second part is focusing on the structural assessment of historic timber roofs. First, they are approached as an independent system with the main scope to identify parameters which are important to be considered during numerical simulations. Secondly, the roof structure is considered as part of the building, and the influence of the roof structure on the structural behaviour of the building during seismic events is analysed.

3. Ultimately, the last part considers all the observations and conclusions drawn from the first two parts and represents an assessment methodology proposal which can be used to determine the value of a roof structure from multiple points of view and its vulnerability.

The first chapter presents a general overview of the thesis and highlights its main scope and topics. Considering the complexity of historic timber roof structures and the diversity of factors which ultimately influence their value, the main objective of the thesis is to increase the knowledge concerning historic timber roof structures. This is done, not only by looking at them as structural systems but as part of a more complex system where all the surrounding and composing elements are interlinked and are influencing each other from an aesthetic, symbolic but also a structural point of view. Therefore, the scopes of the thesis are:

1. The analysis of current, international assessment methodologies and procedures in order to identify the main differences between them
2. The identification of additional features which have to be taken into consideration when assessing the value and vulnerability of historic timber roof structures starting from the already developed methodologies and respecting the ICOMOS recommendations and principles
3. Performing a desk and on-site survey of selected roof structures from Timisoara, from different periods and contexts
4. Highlighting the importance of addressing the value of roof structures from different points of view
5. Understanding of the way current meteorological conditions and future climatic changes can affect the state of conservation of the roof structure elements and roof structures as a whole and identification of features which are influencing the response of the roof structure when subjected to extreme meteorological events like high wind velocities;
6. Calibration based on analysed experimental tests from the literature of a roof structure, in order to identify parameters which must be considered during linear finite element simulations
7. Understanding of the role of timber roof structure types from Timisoara on the seismic behaviour of historic masonry structures, by comparing the different effects of the selected roof structures in terms of horizontal displacement, inter-story drift, damage level of the historic masonry structure, deformed shape of the building and internal forces
8. Understanding of the effect of the decay of the timber elements on the influence of the selected roof structures on the seismic behaviour of the considered historic masonry building by comparing the same parameters
9. Highlighting the importance of considering a multi-, inter- and transdisciplinary assessment when addressing historic timber roof structures and development of an improved assessment procedure which can be used to determine the general value and vulnerability of historic timber roof structures, considering the value of the roof structure from an urbanistic, architectural, symbolic and structural point of view and vulnerability caused by climate change and its decay which is also highlighting the effect of the assessed roof structure type on the seismic behaviour of the building

Chapter two highlights that the assessment of historic timber roof structures is a complex topic which needs to be approached from multiple angles in order to be able to gather all the necessary information about all the features which affected the shape and choice of roof structure type. Besides the fact that they have an essential structural value, representing the knowledge of the timber craftsmen, some structures have a significant aesthetic, architectural and cultural value, due to their appearance and craftsmanship. Since the construction techniques are based on the traditional skills of the craftsmen, each structure becomes unique and special. At the same time, this type of multicriterial assessment is of great importance to properly preserve timber structures with all their valuable elements, both structural and aesthetic and find suitable intervention strategies.

Studies concerning the protection of historic timber structures acknowledge that in order to be able to develop comprehensive assessment guidelines, a holistic approach has to be taken into consideration which can combine data from various fields and therefore help in the decision-making process [1]. At the same time, they also acknowledge that the value of a timber structure is related to several factors like history, aesthetics, science, technology, anthropology or symbolism, features which are also important in correctly understanding the structure [2].

The need to use an interdisciplinary approach when addressing historic timber roof structure is highlighted by various other studies [3–5] which bring the importance of first understanding the architecture of a timber structure and the principles which led to the choice of type and shape forward [6]. They also highlight that the assessment of historic timber structures is a rather complex problem, since timber structures evolved differently in various regions, influenced by the knowledge of the craftsman, but also due to the mechanical properties of the timber and its current state of conservation [7].

Respecting the ICOMOS principles encouraging a multidisciplinary assessment of heritage structures, different assessment methodologies suitable for historic timber roof structures have been developed in recent years, by various task groups of COST Actions or different researcher groups [8–13], in order to ensure the safety of the built timber heritage. Nevertheless, all these methodologies and procedures mainly focus on the roof structure, its on-site assessment [7,8], the analysis of the mechanical properties of the timber elements [1,14] and its static behaviour [15–17], without looking at the roof structure as a part of the building and understanding its connection with everything that shapes and surrounds it. All these methodologies were analysed and all the criteria which are taken into consideration highlighted.

Subsequently different assessment procedures were analysed. Due to the complexity of the assessment methodologies, in order to simplify the evaluation of historic timber structures, different assessment procedures and templates have been developed [18–22]. They highlight that due to their complexity, historic timber structures need an organised framework which is clearly defining the steps which need to be followed and is bringing forward features which need to be addressed during the assessment. By using forms with and without scores or checklists, the assessors can objectively evaluate the main features of the structures, their detail and state of conservation.

Still, these methodologies and procedure, despite being multi-criterial are focusing on the structure as an individual system without looking at it as part of the building and acknowledging the connection, both visually/aesthetically and structurally between all the composing elements of the building.

Starting from the assessment procedures and guidelines developed in these COST actions, it got clear that there is still place for improvement, and that specific criteria related to the aesthetical and architectural value of the roof structures are not adequately taken into consideration.

Therefore, in order to be able to conserve historic roof structures properly, a complex evaluation is needed. The assessment should consider all the factors that influenced the shape of the roof and used structural typology while also considering its aesthetics and the relation with the surrounding urban area. Only after such an analysis, the roof structure can be structurally evaluated and strengthening measures, if necessary, can be taken.

Based on the factors which are taken into consideration in other assessment methodologies and what has been observed to be relevant in defining roof and roof structures in Timisoara a list of features has been identified which should be included in a future proposed assessment methodology and procedure.

1. In the case of urban planning principles, it was observed that there are certain situations in which a roof is highlighted in its urban context or on the contrary, invisible and not playing any role in defining urban space. It was observed that the value of the urban area, the position, frontage, height of the building, the urban alignment and the shape and pitch of the roof are features which are influencing the importance of the roof and determining if the roof structure can stand out in its context or is part of a coherent urban ensemble.
2. Architectural styles and aesthetical principles prove out to also influence the choice of roof. It was observed that the period in which the building was built and the architectural style, the heritage value of the building, its height, main function, but also the roof shape and material used for the roof envelope are features which highlight that the roof is completing the appearance building.
3. Besides the connection to the surrounding urban space and the building, roofs and roof structures also proved out to have a high symbolic value. Based on a complex transdisciplinary analysis of roofs and roof structures based on geometry related studies performed in art and architecture [23–26]. These features are related to the ratio between the roof and the building but also between the position of important structural elements and joints which highlight the influence of the philosophy of the craft-guilds in defining roof structures and can help identify missing elements or altered structures.
4. In the case of structural principles, starting from existing roof structure assessment methodologies, it was observed that a series of features define the structural value of a roof which are related to the general appearance of the structure, the used structural elements and its details. Therefore, features related to structural type and style, truss typology, special structural elements and joint characteristics were considered to be relevant for a future structural preliminary visual assessment.
5. As already highlighted in previously developed assessment methodologies, it is important to determine the state of conservation of roof structures. In the case of a preliminary visual inspection, it is relevant to identify the decay of the exterior side of the roof (ridge, cornice, chimney and roof envelope material) and the decay of the timber elements which can be affected by humidity.
6. The analysis also highlights that meteorological factors like wind, hail and rain/humidity and above all climate change are a real threat for both roof structures in a good state of conservation but mainly for those already presenting signs of decay. It is, therefore, necessary to understand their effect and include them in future assessment methodologies and procedures in order to acknowledge the threat and find solutions to mitigate their effects.

Chapter three brings forward that timber roof structures are highly neglected when performing assessments of historic buildings, due to their complexity, the inhomogeneous properties of the material and high uncertainties regarding the state of conservation and mechanical properties of the timber. Still, they are proof of the skills of the craftsmen and should be understood in order to ensure their protection for future generations.

However, the misunderstanding of historic timber roof structures can lead to a partial or complete unnecessary replacement of the structure [27]. This is why, in order to ensure their protection, they have to be appropriately analysed from various points of view. Their behaviour is related to the mechanical properties of timber [27–30], the behaviour and stiffness of timber joints but also the geometry of the structure and composing structural elements.

The thesis is further on analysing a series of recently performed on-site assessments of historic timber elements using destructive and non-destructive tests [31–37], as well as laboratory tests on full-scale timber roof structures and timber joints [38–43], highlighting that due to the dimensions of roofs, only a few tests were performed on complete trusses while most of the tests are focusing on understanding the behaviours of several types of timber joints.

Seven laboratory tests are analysed, a queen-post truss in Trento [44], two king-post trusses in the Pergine Valsugana village in Italy [45–47], a queen-post truss in Avanca, Portugal [48], on truss from a warehouse roof structure, also from Avanca in Portugal [49], four trusses from Coimbra in Portugal [50–53] and four king-post trusses from Italy [54]. All these tests were performed on historic timber trusses which were rebuilt in the laboratories using the same traditional techniques and subjected to vertical, symmetric or asymmetric loads, in order to understand the load transfer and their structural behaviour. At the same time, since non-destructive tests can offer vital information concerning the structural integrity and bearing capacity of the timber elements [34], all the analysed laboratory tests were preceded by preliminary non-destructive analysis of the historic timber.

Subsequently the focus is shifted towards the analysis of the modelling of historic timber joints, since all the studied laboratory tests highlight the importance of adequately addressing the semi-rigid behaviour of historic timber joints and their effect on the behaviour of the structure. The used joinery types are complex and are influenced by the knowledge and experience of the craftsman and are therefore difficult to analyse using contemporary methods. Therefore, in order to understand the importance of the semi-rigid joints on the structural behaviour of a analysed timber truss, three different methods were identified and analysed, which are commonly used and presented in literature: the component method, a method which is based on the geometric features of the roof structure joints and mechanical properties of the timber [153,154]; the Heimeshoff and Köhler method which only consider the geometric features of the roof structure[14,126] and the method presented by Hölzer [155,156].

Since until today no laboratory tests have been performed on full-scale historic timber roof structures in Timisoara due to their significant dimensions. Therefore, in order to obtain reliable results during numerical simulations, calibrations were performed starting from laboratory tests performed at the University of Trento. The roof structure from a building from Pergine Valsugana village near the Caldonazzo Lake in Italy was chosen for the calibration, a Mediterranean king-post type from the beginning of the 20th century, presenting all the typical features from that area (Fig. 1).

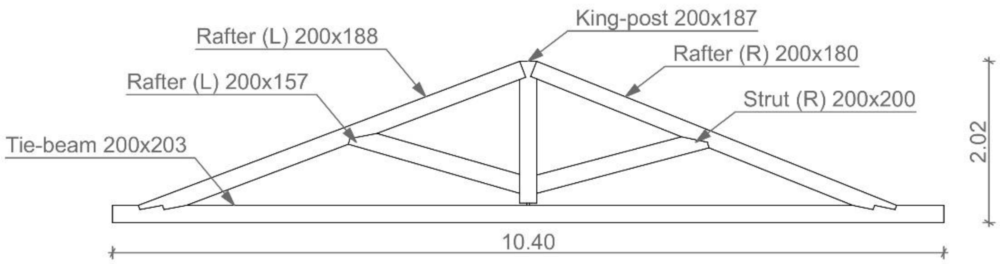

Fig. 1 Roof structure used for the numerical simulations

The analysis of the laboratory test and the subsequent numerical simulations have brought forward a series of approaches but also parameters which have to be taken into consideration when assessing the behaviour of this type of structure. Two important parameters were identified.

1. On the one hand, material and cross-section related properties of the timber elements are significantly influencing the behaviour of the roof structures. It is therefore essential to perform a preliminary visual inspection of the roof structure to identify its decay and possible cross-section loss, and, if it is possible, non-destructive tests in order to determine the mechanical properties of the timber.

2. Timber joints, on the other hand, prove out to also significantly influence the structural behaviour of historic timber roof structures. The used joinery types are complex and are influenced by the knowledge and experience of the craftsman and are therefore difficult to analyse using contemporary methods. By analysing the numerical simulations presented in the literature, it was observed that the joints could be modelled as rigid, hinged or semi-rigid, with or without considering their rotational stiffness. In either way, they ultimately affect the structural behaviour and deformation of the roof structure.

The subsequent calibrations of the finite element numerical models were performed based on the previous observations, and bring forward that:

1. if the joints are modelled as hinged or rigid it is necessary to reduce the cross-section of the timber elements with 15% in order to a similar deformation as observed during the laboratory test
2. if the joints are considered semi-rigid and determined using the component method it is necessary to reduce the cross-section of the timber elements with 15% in order to obtain a similar deformation as observed during the laboratory test
3. if the joints are considered semi-rigid and determined using the Heimeshoff and Köhler method or the Hölzer method it is necessary to increase the calculated axial stiffness of the joints four times in order to a similar deformation as observed during the laboratory test

Considering the performed calibrations all the recorded displacements are in the 20% range of the displacements obtained during the laboratory test, the observations can be further used for other numerical simulations using the finite element software SCIA Engineer (Fig. 2).

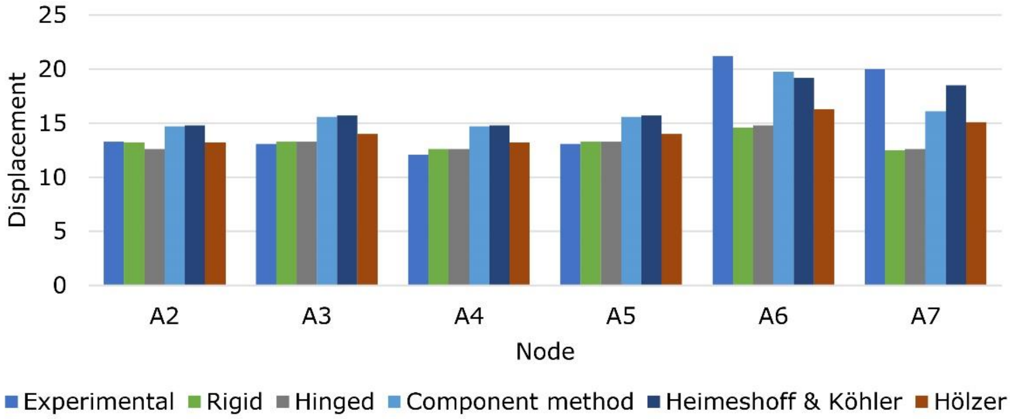

Fig. 2 Comparative displacement analysis of the obtained displacement of each node after calibration

In **chapter four** is focused on the influence of the roof structure on the seismic behaviour of historic buildings. Besides being connected with their urban context, the building is composed of elements which are closely linked, each one of them influencing the aesthetics but also the structural behaviour of the other. Despite this, when assessing heritage buildings, their structural behaviour and seismic vulnerability, professionals usually check the integrity of the main load-bearing structure without looking and considering the effect of the roof structure on its global behaviour.

Studies performed on the role of historic roof structures in the structural behaviour of heritage buildings highlight the fact that their presence can, depending on the type, enhance the structural behaviour of a building but can also lead to significant damage if the connection to the wall is decayed or was poorly designed [55–59] (Fig. 3). At the same time, the beneficial effect of the mechanical properties of timber inserted in historic masonry structures is highlighted in numerous studies, mainly performed in seismic areas [60–62].

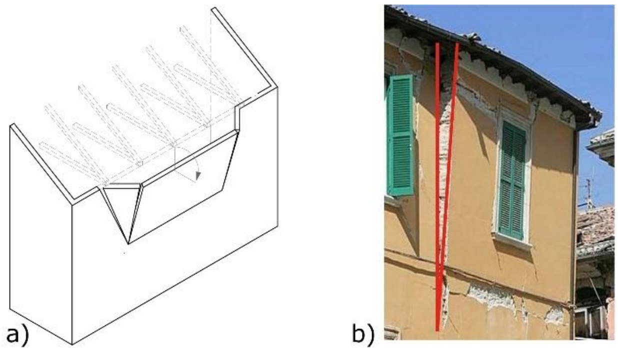

Fig. 3 a) Out-of-plane failure mechanism; b) Out-of-plane failure after the L'Aquila Earthquake (2009) (after [63])

Therefore, in order to also understand the link between the roof structure and the building it belongs to, an 18th-century building from the city centre of Timisoara was considered, on top of which three different types of roof structures were placed, which are characteristic for this city. The main scope was to understand and be able to compare the effect of these types of common roof structures from Timisoara on the seismic behaviour of the chosen historic masonry building [167,168]. The finite element analysis software SCIA engineer [64] was used to perform the numerical simulations. Despite being more conservative, the seismic Equivalent Lateral Forces (ELF) method was used to perform the seismic analysis of the building with and without roof structures.

Due to the complex nature of the connection between the roof structure and the historic masonry wall and since this connection is relevant in the seismic behaviour of the building, three different support typologies were considered for the numerical simulations: rigid supports, representing a rather conservative approach, sliding supports with a horizontal axial stiffness of about 50 kN/m can be assumed in the direction of the trusses and 10 kN/m along the wall [65] and hinged supports on one side of the building and sliding supports on the other side. By considering these three support scenarios, it was possible to understand how a very rigid connection or a connection which only considers the friction between the roof and the wall may influence the behaviour of the historic building during a seismic event.

Subsequently, the traditionally crafted timber joints were considered for each of the support scenarios as: rigid, hinged or semi-rigid joints considering the three methods previously described (component, Heimeshoff and Köhler and Hölzer methods).

In this way, both simple analyses using rigid or hinged joints were taken into consideration but also a more time-consuming way of determining the axial stiffness of the joint was used. The main scope was to understand how each type of joint is influencing the relationship between the roof and the building. Considering this, 15 scenarios were created, influenced by the support type and joint typology.

Subsequently, since the roof structures were built in the 18th, 19th respectively in the 20th century, although they were in a good state of conservation without any major decays, it was considered that the study should have also have a second step where the roof structures are considered decayed. According to other studies, when performing numerical simulations concerning historic roof structures, a reduction of the cross-section of the timber elements should be taken into consideration, due to the rounded edges and possibly decayed outer layer of the timber elements. The studies state that a reduction of 15 up to 20% can be expected [50]. This is also consistent with the observations made during the calibration process presented in chapter 3, where a cross-sectional reduction of about 20% was considered in order to obtain similar results as during the analysed laboratory tests.

For each model and each scenario, five parameters were assessed and compared first with a hypothetical case without roof structure. The main scope was to understand which roof structure is or is not improving the seismic behaviour of the building and how the results are connected with the used support and joint type: the out-of-plane horizontal displacement and inter-story drift of each floor; the deformed shape of the masonry building; the recorded damage level of the masonry walls based on the obtained inter-story drift and the internal forces (Vertical axial forces; out-of-plane shear forces and out-of-plane bending moments).

The main conclusions of the analysis are that:

1. In all the scenarios, the differences between the effect of each roof structure are highly influenced by the roof structure type and its state of conservation.
2. It was observed that in a good state of conservation, the presence of the roof structure is:
   2.1. Reducing the top horizontal displacement between 10 and 55%.
   2.2. Reducing the inter-story drift on the last floor between 5 and 85%.
3. In the case of a significantly, up to 20% decayed roof structure, its effect on the seismic behaviour of the historic masonry building is slightly different:
   3.1. Reducing the top horizontal displacement between 25 and 50%.
   3.2. Increasing the horizontal displacement with 10 up to 20% on the lower floors.
   3.3. Reducing the inter-story drift on the last floor between 25 and 85%.
   3.4. Increasing the inter-story drift with 10 up to 25% on the lower floors.
4. In both cases the presence of the 18th century roof structure has a better influence on the reduction of the top horizontal out-of-plane displacement and inter-story drift, than the other two types, the 20th century one presenting the lowest reduction.
5. Significantly reducing the damage level on all floors of the building.
6. Changing the deformed shape of the building from flexural, as recorded in the no roof structure case, to shear, in the case of the 18th and 19th century roof structure.
7. Concerning the internal forces recorded on the masonry wall, it was observed that:
   7.1. Tensile axial forces can appear at the top of the building.
   7.2. Shear forces perpendicular to the wall and out-of-plane bending moments can suffer an increase at the top of the building.
   7.3. Shear forces with a reverse direction appear in the area of the cross-vault
   7.4. Out-of-plane bending moments present an increase at the top of the building but lower values at the base of the top floor.

The **fifth chapter** is based on the observations that roofs, roof structures, are highly influenced by to their context and the building they belong to, have a significant value, which is not always linked to their structural characteristics and the joint properties. The overall value and vulnerability of roof structures may be increased, or on the contrary decreased by their immediate context, the urban planning principles, architectural features or even symbolic factors. In addition to these features, the study brought forward that in order to accurately determine the structural vulnerability of historic roofs, their state of conservation and the effect of current and future climatic conditions should also be taken into account. Ultimately, as clearly highlighted in chapter 4, the studies also show that considering the roof structure type and its state of conservation, it may improve the seismic behaviour of the historic masonry building.

Consequently, based on the observations, a holistic procedure for a comprehensive assessment of historical roof structures was developed, based on a multi-, inter- and transdisciplinary assessment, taking all the factors surrounding roof structures into account and respecting in this way the ICOMOS and ISCARSAH principles.

The assessment of features influencing the appearance of roofs and choice of roof structures brought forward that four main categories have to be taken into consideration when assessing their global value:

1. The urban value;
2. The architectural value;
3. The symbolic value;
4. The structural value.

At the same time, their vulnerability is highly influenced by environmental factors, leading to the decay of the timber elements, of the roof envelope material and the general appearance of the roof and building. Therefore, in order to determine the vulnerability of a roof structure, the following parameters should be taken into consideration:

1. The state of conservation of roof structures;
2. Climate change-induced damages.
3. The influence of the roof structure typology on the seismic behaviour of the building, based on the observations made during the numerical simulations.

The procedure was therefore classified into five assessment levels, each one of them organised in a tree-like structure. Each level contained criteria considered relevant for the assessment and a list of responses to choose from, for each criterion. Ultimately, to ensure the objectivity of the assessment, for each response of the procedure, a specific score was proposed. The score is one of the personal contributions of the research. It was determined based on the preliminary assessment of features influencing the value of a roof structure from all the point of views, considering the coherence of the context, value in the historic area or building, uniqueness of the structural elements or symbolic features.

Based on this proposed score, the procedure can automatically determine:

1. The urban value score of the roof structure;
2. The architectural value score of the roof structure;
3. The symbolic value score of the roof structure;
4. The structural value score of the roof structure;
5. The predominant value of the roof structure;
6. The ideal value of the roof structure;
7. The decay index of the roof structure;
8. The real value of the roof structure;
9. The climatic vulnerability of the roof structure;
10. The influence of the roof structure on the seismic behaviour of the building;

After selecting the suitable response for each of the assessed criteria, the procedure is automatically analysing each response and calculating its corresponding score. Every level of the assessment can obtain a maximum score of up to 100 points which are equally divided between all the assessed criteria of the considered level. In order to be able to perform and quick and easy assessment of a roof structure by using the proposed assessment methodology two different forms were developed, one which could be filled out by using a computer or laptop and the second one which is a mobile application and has the advantage that it can be filled out even on-site.

In order to validate the proposed vulnerability assessment procedure, 18 roof structures from various neighbourhoods of the city were chosen: the city centre, the Iosefin district and Fabric district (Fig.4). The roof structures were chosen from different periods, different contexts and belonging to buildings with different functions, in order to capture the changes of the predominant, ideal and real value and their vulnerability better. The roof structures were assessed from all the relevant point of view and all the obtained data introduced in the assessment form.

The context in which the chosen roof structures were built are entirely different and are marked by the character of each district. While the centre had from the beginning a more urban aspect, the other two districts were former villages, which suffered significant changes at the end of the 19th century, beginning of the 20th, when they were connected to the old fortress, and they became neighbourhoods of the new city [66,67]. This is why different types of buildings, roofs and roof structures influenced by different principles were identified in these three areas.

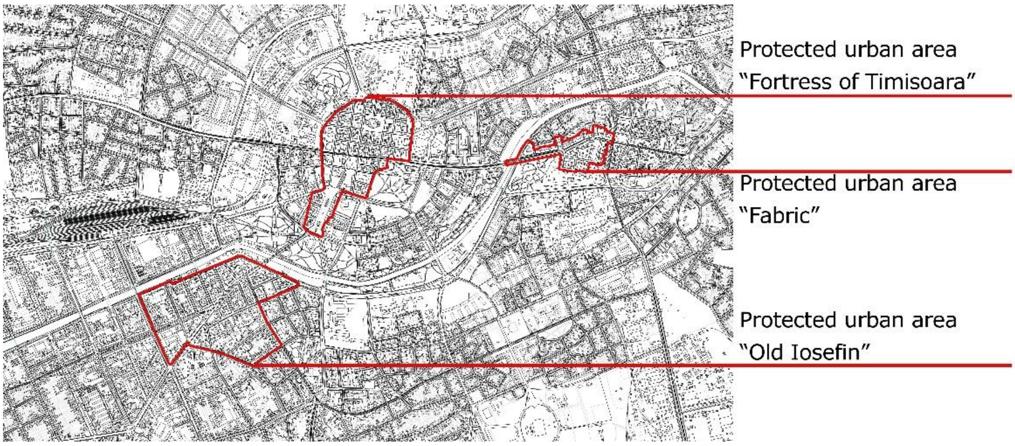

Fig.4 Protected urban areas where the assessed roof structures were chosen

From the three considered neighbourhoods of the city, after the assessment of each roof structure from all the points of views, four roof structures were selected, which were representative for each of the four assessment levels. The scope was to see if the assessment form will recognise the same predominant value as the performed preliminary assessment.

Subsequently, all the other 14 assessed roof structures were analysed in the same way as the reference roof structures and all the observations introduced into the assessment form. In order to better understand the importance of the roof structures from all the point of views, the buildings were sorted based on their construction year, and the obtained results compared for each assessment level. In this way, the evolution in time of the assessed principles could be observed and identified if specific trends are visible.

Due to the fact that the procedure approaches roof structures by using a multidisciplinary, transdisciplinary and interdisciplinary analysis, and addressing their link to the immediate urban space, its relationship to the building, its symbolical features and structural characteristics, it can be used as a preliminary assessment tool, before the actual structural analysis of the roof structure. Since it is offering information about the value and vulnerability of roof structures it can be also used as a fast and cost-efficient decision-making tool.

The methodology described in the thesis is a first step in defining a holistic assessment of historic timber roof structures. The assessed criteria and responses to choose from were developed and confirmed based on the analysis of historic roof structure from Timisoara and local climatic conditions and risks but also based on other assessment methodologies identified in literature. It can, therefore, be developed in the future from all points of view and additional criteria added based on future observation. At the same time, the framework can also be used in other cities, but an adaptation of the score and replacement of specific assessed criteria or responses with local ones might be necessary.

Finally**, the sixth chapter** is presenting a summary of the results, the conclusions of the thesis, main personal contributions and a complete presentation of the research dissemination in conference and journal papers and their citations. At the same time, the chapter also presents an outline of possible future studies related to the assessment of historic timber roof structures and their effect on the seismic behaviour of historic masonry buildings.

It is once again highlighting the need of looking at historic timber roof structures from a multidisciplinary point of view respecting in this way the principles and recommendations of the Venice Charter and ICOMOS principles. It is therefore highlighted that urban planning principles, architectural styles, symbolic and geometric ratios and complex structural features are ultimately influencing the value of a roof structure. At the same time, the vulnerability of these structures to various threats is also brought forward by acknowledging the effect of current meteorological conditions and future climatic changes on the state of conservation of the roof structure elements and roof structures as a whole.

The main achievements and personal contributions are:

1. A thorough analysis of current international assessment methodologies and procedures;
2. An extensive desk and on-site survey of selected roof structures from Timisoara, from different periods and contexts;
3. Identification of additional features which have to be taken into consideration when assessing the value and vulnerability of historic timber roof structures
4. Analysis of various semi-rigid modelling methods suitable for traditionally crafted joints and identification of the main differences between them;
5. Proposal of a calibrated historic roof structure model based on an analysed experimental test from the literature:
6. Acknowledgement of the effect of selected historic timber roof structure specific for Timisoara on the seismic behaviour of a characteristic historic masonry building from the 18th century and analysis and comparison of 5 different parameters in order to highlight their effect: out-of-plane displacement, inter-story drift, deformed shape of the building, recorded damage level and internal forces on the wall
7. Development of a preliminary assessment procedure, based on historical and visual analysis of the roof and roof structure, which determines the value of the assessed roof structure and its vulnerability which can be used as a decision-making tool for the planning and hierarchisation of future interventions and comprehensive structural assessments. The procedure also includes a corresponding score for each considered answer based on the observations of the performed analysis and formulas for the calculation of each value, decay and vulnerability index
8. Development of a comprehensive and easy-to-use Excel form and mobile application which can be used on site for the assessment of a historic timber roof structure.

Studies concerning historic timber roof structures, their assessment and understanding of their structural behaviour are few, and future developments of the topics presented in this thesis are necessary in order to understand the complexity of these structures properly.

1. Extensive studies have to be performed in the future in order to understand all the features which influence the value and vulnerability of roof structures. The studies have to be extended towards urban planning and architecture related principles, geometrical and current and future climatic threats
2. Development of value and vulnerability maps and clear intervention prioritising guides for roof structures in Timisoara by using the proposed roof structures assessment methodology;
3. Full-scale laboratory tests have to be also performed on local types of roof structures and traditionally crafted joints
4. Additional numerical simulations and corresponding non-linear simulations have to be performed in order to understand the effect of other roof structure types on the seismic behaviour of historic masonry buildings.
5. The in-plane behaviour of the masonry building with the roof structures has to be also analysed;

6. The methodology has also to be developed and adapted for other European cities, by replacing specific assessed criteria or answers with local ones and adapt the corresponding assigned scores.

The research outcomes presented in this thesis have been published journals and conference proceedings:

1. 5 papers in Web of Science indexed journals;
2. 6 papers in Web of Science indexed proceedings;
3. 1 paper in international database journals (SCOPUS);
4. 2 papers in international database proceedings (SCOPUS);
5. 11 papers in international proceedings;
6. 1 paper in national proceedings.

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