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A Brief Insight into Timber Floors in Slovenia with a Numerical Case Study of an Existing Timber Floor

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Abstract: *This paper presents data of typical span lengths, used timber species and timber joist dimensions, and provides useful facts from different literature about timber floors in Slovenia. Additionally, an existing timber floor is checked according to the current building standards in the European Union, the Eurocodes. To prove the reasonability of preserving old timber floors, a possible addition of a concrete plate added on the top of the timber joists is studied. The analysis of maximum allowable imposed loads is carried out for different span lengths of the timber and the timber-concrete composite floor.*

Keywords: *building renovation, timber floor, Slovenia, numerical case study, timber concrete composite floor, Eurocodes*

1. INTRODUCTION

Timber floor reconstruction is becoming an important segment of building renovation. A frequent situation in building renovation is the change of the category of use. In certain cases, such renovation can lead to the requirement of higher loads, which calls for the structural improvement of the existing structure. Acquirement of existing timber floor data is necessary for planning effective strategies for building renewals. The first part of this article provides different data of timber floors in Slovenia. The second part presents a case study of an existing timber floor. Roof leakage damaged the timber floor which is why it is going to be replaced with a concrete floor. We used the original timber floor geometry and characteristics, to show the potential of strengthening existing timber floors. The purpose of this article is to simply encourage the renovation trend and not calling the replacement of the considered timber floor in question. Other important timber floor criteria such as acoustic properties, fire safety and thermal conductivity are not covered in this article.

2. TIMBER FLOORS IN SLOVENIA

The territory of the Republic of Slovenia was for a relatively long time a part of the Austro-Hungarian Empire. As a consequence, it could be estimated that the timber floors in buildings built before the First World War are at least similar to those in other parts of (Central) Europe. Brezar[1]writes about the so called 4-meter syndrome in European buildings, claiming that the most common span of European rooms is 4 meters which is a consequence of different practical criteria such as easy transport or handle ability. Brezar [1]also speculates that the dimension of a typical timber floor joist cross section is 18 cm x 24 cm. Timber species typically used for timber floors were determined by their availability. As spruce is common throughout Slovenia (at least after the 19th century) it was and still is usually chosen for timber floors[2]. On the other hand, in the Rajhenburg Castle, Brestanica, Slovenia, oak was used [3]. In the "houses of the border counties"in Kranj, Slovenia, even walnut trees were employed for the timber floor from 1638[4]. Nevertheless, Hazler [5] and Novak [6]separate the Slovenian territory to four ethnological regions: the Alpine region, the Pannonian region, the Mediterranean and the Central region. Furthermore, Hazler [5] listscommon timber species used in architecture:

- Alpine region: spruce, fir, larch, oak and chestnut trees
- Pannonian region: oak, beech, alder, hornbeam, acacia, hazel, spruce

- Mediterranean region: oak, spruce, other conifers
- Central region: spruce, beech, oak

As a conclusion we may also say that timber floors were built with these species, butnot necessarily with all listed species. Hazler[5]also mentions that larch and spruce timber was usually used for timber floor joists in the Alpine region. Oak and walnut timber was used in the Central and Pannonian region. The oldest known timber floor in Slovenia is located in the Alpine region, that is to say in the "Hlebanja homestead" in SrednjiVrh, Slovenia.The year 1506 is carved out on one of the pine timber joists [7,8].

Although other materials, such as cast iron and concrete, begun being used for floors in the late 19th century (due to forthcoming industrialization), timber floors still kept a significant role. A great example is the building of the "Intes mill" in Maribor, Slovenia, where the load bearing columns and floor joist were made out of timber, even though the loads in mills are relatively high and cast iron was already used in similar buildings at the same time [9]. It is worth mentioning that even nowadays, about 58.5% of the Slovenian territory is covered in forests [10]. As a result, timber was and is still available in relatively large amounts, which makes it economically interesting. On the other hand, these amounts are not limitless, soin 1956 Valentinčič[11]writes about alternative materials which could be used instead of timber. We can conclude that timber was still frequently used for construction and for floors in the time after the Second World War. The reason for subjective expressions for the estimation of timber usage for floors lies in the lack of data about the floors of the Slovenian building fund. Probably the biggest obstacle in data collecting is logical, as timber floors are commonly covered on the top and bottom side and usually need to be uncovered to check the actual state, which is a time and money consuming procedure. The uncovering ordinarily only happens during renovations (Figure1). One way to overcome this problem is to use non-destructive methods, whichare not yet a standard practice. However, Arnuga[12]speculates that 5 % of the Slovenian housing fund has timber floors that need renovation.

Figure1.*Time consuming examination of a timber floor*

2.1. Replacement of Timber Floors in the Past and in the Present

A favourable approach to timber floor renovations in Slovenia is to actually demolish the timber floor and to build a new concrete floor. One would think that the trend of demolishing timber floors and building new floors did not arise before the discovery of cast iron and concrete, but it seems that this trend is much older. Namely, replacements of timber floors with stone and masonry vaults are described in some sources. Lavrič [13]mentions examples of timber floors in churches of the Ljubljana bishopric being replaced by stone vaults, for instance a visit of the Bishop Rabatta to a church in Bled, Slovenia, in the year 1665. The Bishop was informed that the timber floor of the church was going to be replaced by a vault made of tuff. He answered that this procedure would be expensive and would require master-builders for successful accomplishment of this task. He even said, that the church was wide and therefore hard to span with a vault, and also the resulting horizontal forces might be too high for the walls. Another source to support the statement about vaults replacing timber floors is Anon[14], who writes that after the year 1720 masonry vaults were frequently used to replace cassette ceilings.

3. NUMERICAL CASE STUDY OF AN EXISTING TIMBER FLOOR

The following numerical example deals with an existing timber floor (Figure2) at the “Zgornja Polskava Manor”, Zgornja Polskava, Slovenia. The timber floor was painted on its bottom side (Figure2), although some other structural members were covered with a reed plaster (Figure3). The responsible authorities decided to completely demolish all of the existing timber floors and to replace them with concrete floors. It was estimated that the existing timber floors were damaged too much (

Figure4) to undergo renovation. The main reason for the damage was roof leakage. The exact age of the timber floor is not known, but we can assume that it is older than the current building standards, the Eurocodes.

Figure2. *Timber floor bottom view*

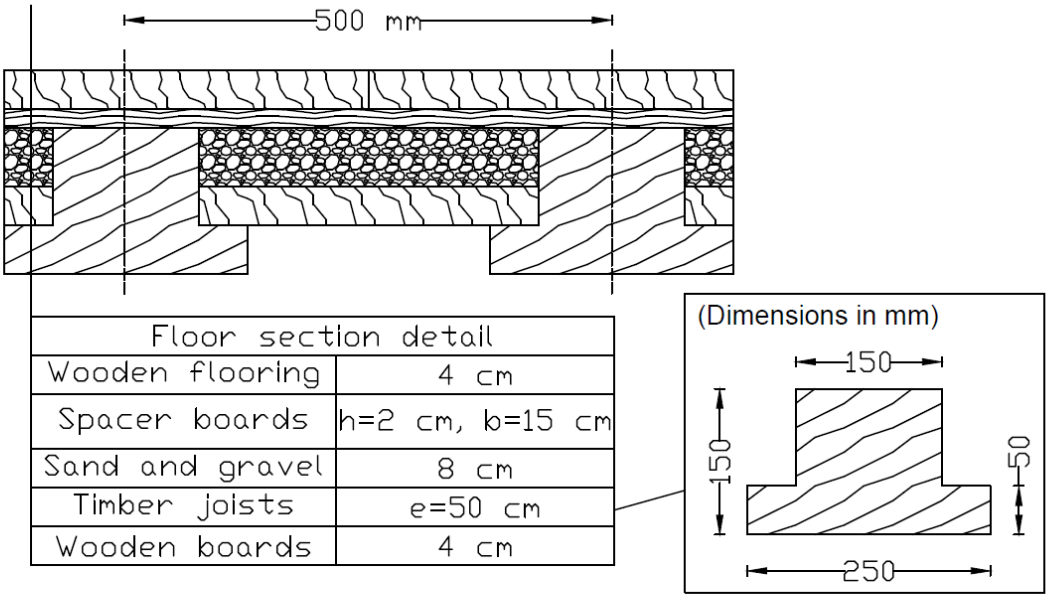
Figure3. *Timber beam with a reed plaster*

Figure4. *Damage due to roof leakage*

As already mentioned, timber floor demolishment provides an opportunity to examine and to collect data on existing timber floor properties. We decided to make a structural calculation of the existing timber floor and examine the effect of a concrete plate addition on the top of the existing timber floor. The mechanically joined timber joists and concrete plate present a composite section. Steel dowels were defined for the mechanical connection.

3.1. Floor Section

The floor section is given inFigure5. The wooden flooring is fitted on spacer boards, which are oriented perpendicularly to the timber joists and have an axial distance of about 1 meter. The space between the spacer boards and timber joists is filled with a mixture of sand and gravel. Timber joists with an inverted T cross section (Figure6) have the load bearing function and an axial spacing of 0.5 m. The function of the lower wooden boards is to simply hold the floor fill in place.



Floor section detail	
Wooden flooring	4 cm
Spacer boards	h=2 cm, b=15 cm
Sand and gravel	8 cm
Timber joists	e=50 cm
Wooden boards	4 cm

Figure5. *Floor section detail*

Figure6. *Timber joist cross section (already demolished floor)*

3.2. Structural Calculation

To judge the load bearing capability of the given timber floor, we made an analysis according to Eurocode 5 [15]. As it is a standard procedure, only few calculation details are provided. Timber type was spruce, so we used the properties of timber class C24 and serviceability class S2. The density of timber class C24 is 420 kg/m^3. The density of the fill (sand and gravel) was said to be 1300 kg/m^3. The calculated area mass of the timber floor was 125 kg/m^2. The span of the floor was 4.5 m. The building was so far used as a residential area, defined by Eurocode 1 [16] as category A (floors) with a prescribed imposed load of 2 kN/m^2. The category of use is about to be changed from residential area to area without obstacles for moving people, which is the category C3 in Eurocode 1 [16] with a prescribed imposed load of 5 kN/m^2.

We performed calculations for different span lengths, different ultimate and serviceability limit states criteria. The results were plotted in order to get a wider picture of the structural behaviour. The combination factors for category C3 were used. Additionally, the final deflection was calculated also for the category A. Deflections from shear deformations were not considered. The calculated final deflection takes timber creep into account.

The criteria were:

- Ultimate limit state – Bending
- Ultimate limit state – Shear
- Serviceability limit state – Instantaneous deflection (deflection limit: span/300)
- Serviceability limit state – Final deflection (deflection limit: span/250)
- Serviceability limit state – Final deflection (deflection limit: span/250) – Category A (floors)

3.3. Results

Figure7shows that the most critical criterion is the final deflection. The maximum allowable imposed load for our timber floor is about 1 kN/m^2 regarding the serviceability criteria. Almost the same applies to categories C3 and Abecause the weight of the floor is 1.25 kN/m^2, which is more than the calculated allowable imposed load. Consequently, the deflections from the floor weight take the leading role and are the same for both categories. If the floor was used for category A (floors), only the SLS final deflection criterion would be violated, as the maximum ultimate criterion load is about 4 kN/m^2, and the SLS – instantaneous deflection criterion loadis 2 kN/m^2, which is the same as the characteristic value for category A. However, regarding our chosen category (C3), the maximum calculated allowable imposed loads from the ultimate and the serviceability criteria are too low, only the ULS criterion for shear strength is met and seems to be the most uncritical. To conclude, we can also see that the SLS criteria are most critical for spans greater than 2.5 m, for spans shorter than 2.5 m the ULS criteria are more critical, especially the ULS – Bending criterion.

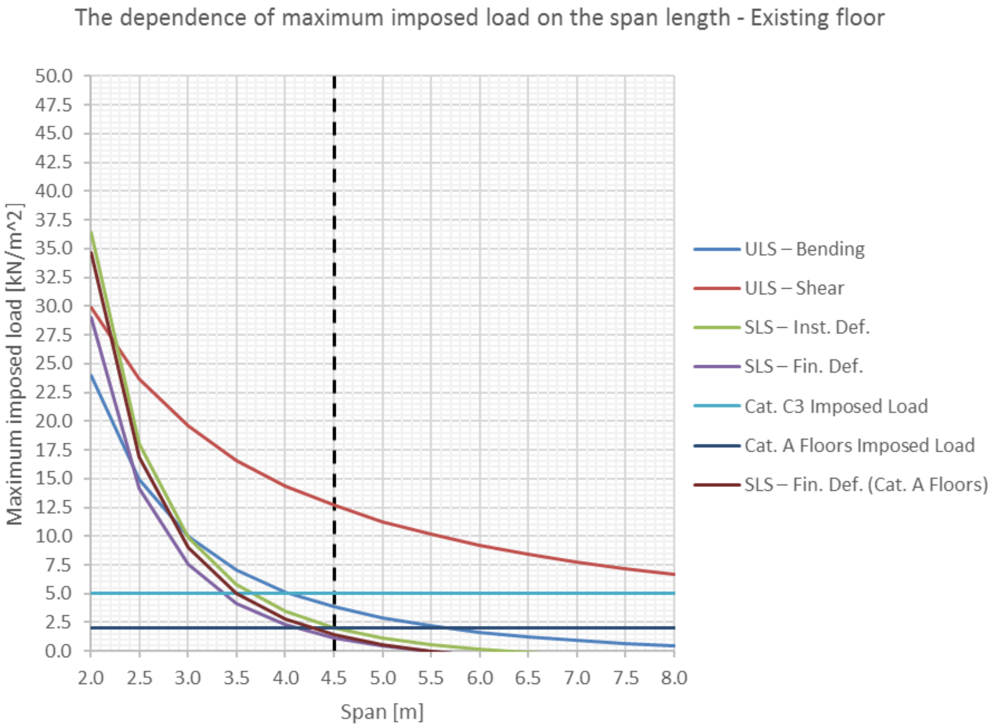


Figure7. *The dependence of maximum allowable imposed load on the span length – Existing floor*

3.4. Comparison to a standard timber floor

For comparison we performed the same calculation for standard timber floor members with a height of 28 cm, width of 10 cm and axial spacing of 50 cm. In addition, the timber class was C24 and the area mass was the same as for the existing timber floor (125 kg/m^2).The results are collected in Figure 8. We can see that the ULS and SLS criteria are met. Furthermore, the maximum span length for the standard floor, still meeting the ULS and SLS criteria, is 5 m. The comparison with the actual floor shows that for the standard floor the ULS – Bending criterion is the decisive criterion for spans shorter than 4 m and that the ULS – Shear criterion is the decisive criterion for spans shorter than 2.75 m. We can conclude that this behaviour difference results from different joist height to width ratios (the ratio for the actual floor is lower than the ratio of the standard floor).

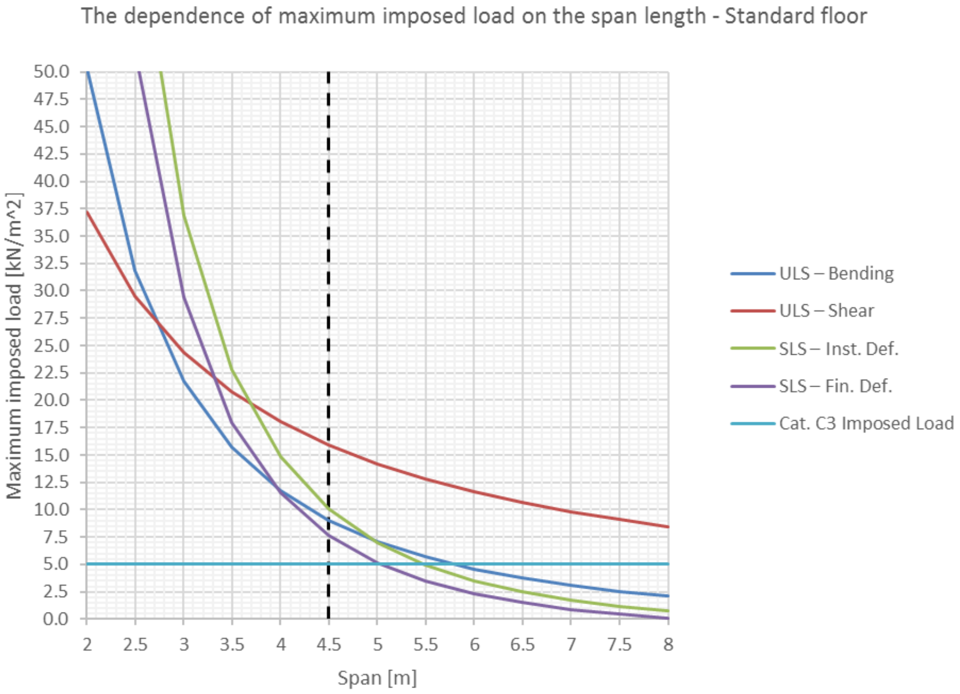
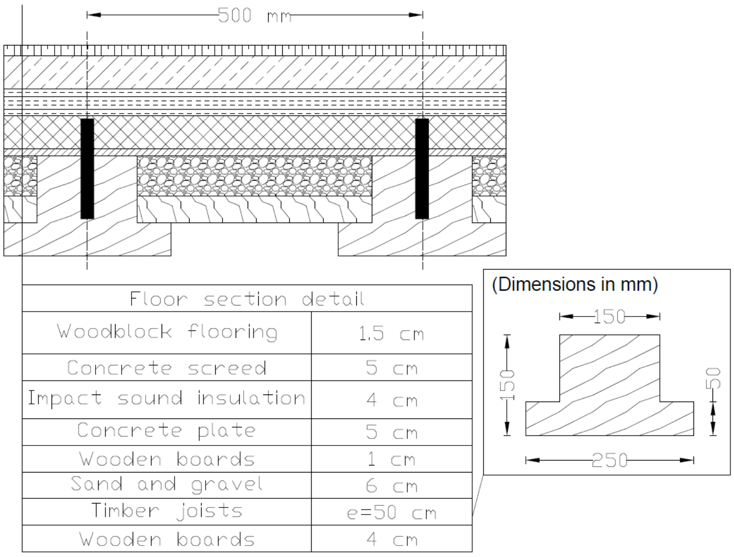


Figure8. *The dependence of maximum allowable imposed load on the span length – Standard floor*

3.5. Comparison to a timber concrete composite floor

As we saw from the structural calculation, the existing floor did not meet the ULS and SLS criteria. We decided to check the effect of a possible addition of a concrete plate on the top of the timber joists. The result of such an addition is a so called timber concrete composite floor. The new floor section with all details is given in Figure9. We removed the wooden flooring with spacer boards and added wooden boards for the needs of concrete pouring. There was an impact sound insulation layer and a floating screed with a woodblock flooring on the top of the concrete plate. The area mass of this floor is about 333 kg/m^2. The mechanical connectors between the concrete and timber part are steel dowels with a diameter of 20 mm and spacing of 10 cm. The connectors were only used for stiffness calculations and were not structurally checked. The calculations were performed in compliance with the so called "gamma method" from Annex B of Eurocode 5 [15].Concrete strength class C30 according to Eurocode 2 [17] and a concrete creep coefficient of 2.8were chosen. Only the shear capacity of the timber joists was used, which means that the results for the maximum imposed load from the ULS – Shear criterion are conservative. The weight of the whole floor should be initially resisted only by the timber joists, however, due to creep, a part of the floor weight was finally resisted by the composite section. The imposed loads were said to be completely resisted by the composite section. Consequently, we had two ULS – Bending criteria: one before creep and one after creep (of both materials). The ULS criteria depend only on timber strength, as the calculation showed that the concrete compression strength is never exceeded. As concrete fails under tension, the un cracked concrete height was calculated iteratively (if the first step of the calculation showed tensile stresses in the concrete plate). Already existing deflections of the floor were not considered.



Floor section detail	
Woodblock flooring	1.5 cm
Concrete screed	5 cm
Impact sound insulation	4 cm
Concrete plate	5 cm
Wooden boards	1 cm
Sand and gravel	6 cm
Timber joists	e=50 cm
Wooden boards	4 cm

Figure9. *Timber concrete composite section detail*

We can see from Figure10 that the most critical criterion for the composite floor is still the final deflection. The maximum allowable imposed load regarding the SLS – Fin. Def. criterion for the timber concrete composite floor is about 6 kN/m^2, whereas for the ULS – Bending after creep criterion (ULS Bending Fin.) the maximum allowable imposed load is about 6.4kN/m^2.We can also see that the ULS – Bending criterion is the decisive criterion for spans shorter than 4.4 m. The ULS – Shear criterion is the most uncritical, even after the shear load is (numerically) completely resisted by the timber joists. Figure10 also shows that after the calculated maximum allowable imposed loads fall under 3.33 kN/m^2 (the weight of the floor), the calculated ULS – Bending criteria loads are getting identical, which is probably a consequence of timber creep mostly resulting from floor weight (dead load). The results from the SLS – Deflection criteria are not becoming identical, but still show similar behaviour as the difference between them is becoming smaller for greater spans and consequently for higher floor weight to imposed load ratios. According to our chosen category of use, the calculated maximum allowable imposed loads from the serviceability and ultimate criteria are high enough for the category C3.The maximum span for the floor to still meet the criteria is only about 4.7 m, although, as already said, the concrete compression strength is not even nearly exceeded. This is probably a consequence of the concrete plate only strengthening the compression zone of the composite section. For better results strengthening of the tensile zone is needed as the timber tensile and bending strength limits the positive effect of the timber concrete composite section.

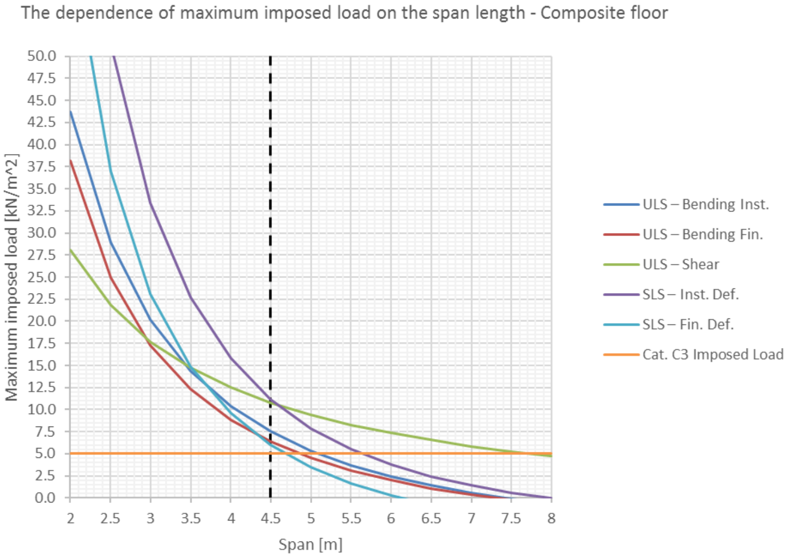


Figure10. *Dependence of the maximum allowable imposed load on the span length – Timber Concrete Composite Floor*

4. CONCLUSION

The main aim of this article is to provide an insight into the field of timber floors in Slovenia. Although the literature research showed a lack of timber floor data, some relevant facts could be found and are presented in this paper. The numerical example of an existing timber floor showed that the load bearing capacity of timber floors could be successfully improved. As a result, atimber concrete composite section, resulting from an addition of a concrete plate on the top of existing timber joists, could meet the current building standard requirements. The calculations for the composite section also indicate that the positive effect of the added concrete plate is limited by the timber tensile and bending strength. The findings of this article should encourage responsible authorities to preserve the originality of old timber floors or to re-build old timber floors in a modified way, similar to the timber concrete composite section.

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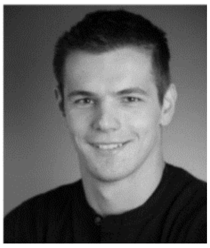

Žiga unuk, graduated at the Faculty of Civil Engineering, Transportation Engineering and Architecture University of Maribor, in 2014. In November 2017he started his PhD studies and started to work as a junior researcher.

Prof. dr. Miroslav Premrov, was granted the title of full professor at the University of Maribor in January 2009. From 1999, his major focus of research has been the strengthening of timber-frame buildings, supplemented by the area of their energy-efficiency, primarily through the increased glazing sizes. He is the author or co-author of 40 research papers indexed by SCI and reviewer for the most reputable international journals from the field of civil engineering structures. He is an editorial board member of three international journals with an impact factor. He is a co-author of a patent of a strengthened wall element. Since year 2010 he is very active in many research and professional projects focused in developing new concepts in energy efficient timber-glass buildings. Main findings are published in two international scientific monographs »Architectural design approach for energy efficient timber frame public buildings« (published in 2011) and »Energy-efficient timber-glass houses« published by Springer in 2013, which was selected by Slovenian research agency (ARRS) as the best scientific contribution in civil engineering in Slovenia in this year. From the year 2012 he is a head of the Slovenian research team of the international FP 7 project Wood Wisdom entitled »Load-bearing timber-glass composites« and a head of the WP 6 »Testing on life-size specimen components«. As a member of WG 5 he is active in preparations of Slovene standards in the field of timber structures. He is also a co-author of a new numerical method for the racking resistance of timber-framed walls proposed to be implemented in the Eurocodes (CEN/TC 250/SC 5 N 638).

Associate professor Dr. Vesna Žegarac Leskovar, born in 1974, graduated at the Faculty of Architecture, University of Ljubljana, in 2000. She brought her PhD studies to an end in January 2011 at the Faculty of Architecture, Technical University Graz

In the professional field of architecture and spatial planning she was already active at the time of her studies, until 2005 she was working as an architecture engineer in the architectural office Reichenbergarhitektura in Maribor.

In 2005 she started her employment at the University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture (UM FCTA). In 2016 she was granted the title of Associate Professor. In the study year 2013/14 she participated as an invited lecturer at the Institute for spatial planning at the TU Graz.

Her professional and scientific work is oriented towards architectural structures and technologies, energy efficiency, sustainable architectural planning and renewal of the existing housing fund. She is an author of research works indexed by SCI and a reviewer for international journals in the field of energy-efficient buildings.

She published her professional and scientific work in two international journals with the title “Architectural design approach for energy efficient timber frame public buildings” (published in 2011) and “Energy-Efficient Timber-Glass Houses” by Springer Verlag, which was selected by Slovenian research agency (ARRS) as the best scientific contribution in civil engineering in Slovenia for the year 2013.

She is active as a leader of numerous student workshops at UM FCTA and involved in development projects carried out by UM FCTA for the national and European industrial partners. In the period between 2011 and 2013 she led an international project “MOVE for Energy Sustainability” where UM FCTA participated as a project partner. In the context of the international development project WOOD WISDOM NET, entitled “Load-bearing timber-glass composites“, she led the work package WP 3 – Architecture. She is currently taking part in the execution and management of the IQ Home project.

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