Drewno 2020, Vol. 63, No. 205
DOI: 10.12841/wood.1644-3985.336.12

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INFLUENCE OF TOP LAYER DENSITY AND THICKNESS ON HARDNESS OF TWO-LAYER FLOOR ELEMENTS

The subject of this paper is testing the hardness of two-layer floor materials with top layer made of ash wood in tangential cut, and bottom layer made of pine wood, radial cut, with cross wood fibre layout in both layers. Tests were carried out for top layer thickness 6.6 mm, 4.0 mm and 2.0 mm. Strong correlations were noticed between the hardness of floor elements and the density of the top layer for each thickness variant. Overall statistically significant influence of bottom layer density on the hardness of two-layer floor elements was observed in samples whose top layer was 2.0 mm thick.

Keywords: floor elements, ash wood, pine wood, top layer thickness, wood hardness, two-layer floor

Introduction

During the last decades, at the turn of the century, we were observing an increase in the production of parquets (solid wooden floor materials; solid, multilayer with top layer made of wood and mosaic) in Europe, with a collapse in 2008 and 2009, according to EFP data [The European Federation of the Parquet Industry 2017]. Recently, the production of parquets has been systematically increasing. In 2016, it was equal to 80.4 million square meters. In 2016, Poland maintained its position as the leader of parquet production in Europe, having 20.1% of the market share. Total consumption was 77.0 million square meters, but only 5.1% of the total parquets sold in Europe were bought by Polish customers. Due to an increasing demand for parquets, new possibilities for European producers have emerged. The most popular wood species for floor material in Europe is European oak (*Quercus petraea* (Matt.) Liebl. *and Quercus robur* L.), which dominates (80.8%) as a material for solid parquets and as a top layer material for multilayer floors. In such layered floors, the top layer is made of oak wood

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veneer, the middle layer of solid pine wood, and the bottom layer of pine wood veneer. The second most common material is ash wood (*Fraxinus excelsior* L.), 5.7%.

Floor is one of the interior architectural elements that have strong influence on aesthetics, but is exposed to many factors that can cause deterioration of its visual appearance. Floor materials should have good water resistance, high thermal isolation (or, in the case of floor heating systems, sufficient thermal conductivity), acoustic, non-slip and hygienic properties, good aesthetic appearance, scratch and abrasion resistance, and hardness [Kozakiewicz and Noskowiak 2012].

Hardness is a measure of resistance to localized plastic deformation (accompanied by some elastic deformations) induced by either mechanical indentation or abrasion. This property is very important in case of choosing wood as floor material [Niemz and Stübi 2000; Heräjärvi 2004; Kozakiewicz and Noskowiak 2012; Németh et. al 2014; Różańska 2014; Kozakiewicz and Romanovski 2016]. For hardness determination, different methods are used. For example: Brinell and Janka methods, but results of the mentioned methods are significantly different [Starecki 1975; Kollmann and Cöte 1984; Schwab 1990; Kúdela 1998]. According to Schwab [1990], the Brinell method gives reliable results. By using this method, we can find differences in hardness in anatomical directions and along annual growth rings, confirmed in the research of Hirata et al. [2001]. According to research by Kontinen and Nyman [1977], a more appropriate way to calculate indentation is by measuring its depth rather than its diameter as in the original method. Heräjärvi [2004] found no difference between these two variants for hardness determination of birch wood.

The Brinell method is not perfect, indentation diameter along the wood fibres and perpendicular to fibres are not of the same length, as indentation is elliptical in shape, so wood hardness determined with the original method has lower values than when calculated using the variant with depth measurement [Grekin and Verkasalo 2013]. Some researchers try to improve this method or modify it [Niemz and Stübi 2000]. Most researches use the test standard [EN 1534:2000] or its new version [EN 1534:2011; Wang and Wang 1999; Grekin and Verkasalo 2013; Laine et al. 2013; Merela and Čufar 2013; Różańska 2014; Kozakiewicz and Romanovski 2016]. Wood hardness determined with the Brinell method is related to wood density, moisture content and anatomical direction of wood [Kollmann and Cote 1984; Wang and Wang 1999; Holmberg 2000]. According to research conducted by Grekin and Verkasalo [2013], Scots pine wood from Finland is characterized by significant density variation and wood hardness, and wood hardness is directly proportional to wood density with very high coefficient of correlation.

The top layer is made of elastic material, so local pressure, during floor application, coming, for example, from high-heeled shoes or a rigid steel ball, during hardness testing, could generate deformation under the rigid body and around it. The theoretical aspect of half-space contact problems has been analysed by Zhou and Gao [2013]. The top layer deformation and deflection arrow depend on the top layer thickness, elasticity properties and rigidity of the bottom layer.

There are floor products made of HDF and oak veneers at the top. Because of the high hardness of the bottom layer and a thin top layer (1 mm), the hardness of this floor material is about 20% higher than that of solid oak wood.

In Europe, one of the biggest floor materials manufacturer, Barlinek, produces three-layer floor materials. The top layer of a floor panel is made of oak wood, 3,2 mm thick, and the middle layer is made of solid pine wood. The hardness of pine wood is significantly lower compared to oak wood, so in the case of a two-layer material we can observe a reduction in the hardness of floor panels compared to the hardness of solid oak wood.

Other producers of floor materials use birch plywood as the bottom layer of two-layer floor materials. In this case, the difference in the hardness of the top layer made of wood and the bottom layer is not so high, so we can observe a lower reduction in the hardness of floor panels.

The purpose of this research is to determine the influence of a bottom layer made of pine wood on the hardness of two-layer floor elements with the top layer made of ash wood. Ash wood is the second most popular species used for parquets – the first one being oak wood – because its hardness is similar to oak wood hardness. Pine wood is often used for the support layer as a low-cost, highly available material.

Materials and Methods

The floors used for tests were two-layer floors with top layer made of ash wood cut in more popular tangential plane (*Fraxinus excelsior* L.) with more interesting figure and bottom layer made of solid, pine wood cut in radial plane (*Pinus sylvestris* L.) with a share of heartwood from 60% to 90%. The radial plane used in the bottom layer offers a better support for the top layer for cross grain gluing in two-layer floor materials. Therefore some producers of floor materials use this kind of selected softwood. Vertical zones of late wood, which have higher density, are stiffer than horizontal zones of early wood.

Pine wood is a typical kind of wood used for inner and bottom layers of multilayer, real-wood floors. Wood for both layers was free from any structural defects like knots, cracks, rot and insect holes. Layers were glued with glue Ponal SUPER 3, aqueous polyvinyl acetate dispersion. The two-layer floor elements had cross fibre layout like in plywood. Before gluing, density of each layer was determined using stereometric methods according to ISO 13061-

2:2014-10. Hardness of the parquet was determined in three stages, for 6.5 mm, 4.0 mm and 2.0 mm top layer thickness. There were 10 bottom elements, about half meter long, for each of three sets of density, i.e. 400-500 kg/m^3, 500--600kg/m^3 and 600-700kg/m^3. For each bottom element, 5 top veneers of ash wood were glued and thus 150 samples were obtained. For each sample, 3 hardness tests were carried out for the top layer thickness of 6 mm, 4,5 mm and 2 mm. Hardness was first determined for the top layer which was 6mm thick. Subsequently, 5 blocked sample was planned to obtain a 4.5mm thick top layer. The procedure was repeated to finally obtain material for hardness testing with the top layer of 2 mm. Thus, a reduction in the top layer thickness was achieved by a planning operation between the subsequent stages of hardness determination.

The measurement points of hardness testing for different top layer thickness were located close to one another to reduce density changes in ash and pine wood, but taking into account the influence of the reduction observed in earlier hardness measurements. The bottom layer thickness was 24 mm. This size is not used in real floor products, but it was used in the tests to have the bottom layer made of solid pine wood, without the effect of a thin layer supported by a steel plate during the hardness test. The bottom layer in the zone of hardness testing was made of heartwood and sapwood and the average density was determined for these elements before gluing. No significant changes were observed for the hardness of pine softwood and heartwood. The hardness of two-layer samples was determined according to EN 1534:2011 (test method for solid wood).

A 10 mm in diameter, hardened steel ball was used for the tests. A force of 1000 N was applied for 25 s. Hardness was calculated according to the formula (1):

$$\mathrm{HB} = \frac{2 \cdot F}{\pi \cdot D \cdot \left(D - \sqrt{D^2 - d^2}\right)} \tag{1}$$

where: HB – is the Brinell hardness [MPa], F – is the maximum load force applied [N], D – is the diameter of the ball [mm], d – is the diameter of the residual indentation [mm]. (the average of diameters along fibre d_1 and perpendicular to fibre d_2).

Moisture content of wood samples was controlled using the oven-drying method according to ISO 13061-1:2014-10. The total test samples count was 400 for each of the three variants of top layer thickness. Test results were subjected to statistical analysis.

For selected samples, floor elements were cross cut in the zone of indentation, after hardness determination. Surface of samples was sanded to prepare the material for observation and analysis of wood deformation and compression using Nikon optical microscope model SMZ1500.

Results and discussion

Ash wood, as a ring porous hardwood species, is characterized by a high variation in the density of ring zone. The density of earlywood, at absolutely dry state, varies from 385 to 506 kg/m^3, and the density of latewood varies from 721 to 803 kg/m^3. The ratio of earlywood/latewood layer thickness depends on the total annual growth ring. If annual growth ring is narrow, then earlywood layer is thicker than latewood layer. In wider annual growth rings, latewood layer dominates [Kollmann and Cöte 1984]. The density of tested solid ash wood with moisture content about 9% (moisture level accepted for floor materials by EN 13489:2002) varied from 562 to 934 kg/m^3 and average hardness was 39.9 MPa. As a result, hardness, determined with the Brinell method on tangential section of wood also had high diversity, with coefficient of variation equal to 27%.

Pine wood used for the bottom layer had density that varied from 401 to 648 kg/m^3. Average hardness was 18.7 MPa and density 536 kg/m^3. Wood with density from 400 to 500 kg/m^3 (average 450 kg/m^3) had average hardness of 14.0 MPa; with density from 500 to 600 kg/m^3 (540 kg/m^3 on average) – 19.9 MPa; and wood with density over 600 kg/m^3 (626 kg/m^3 on average) – 22.7 MPa, respectively. In all cases, hardness was significantly lower than the hardness of ash wood used in the top layer.

For floors with top layer thickness 6.5 mm, the average Brinell hardness was 42.3 MPa; for 4.0 mm: 38.8 MPa; and for 2.0 mm: 35.6 MPa, respectively (Fig. 1). Linear, directly proportional relationships between the Brinell hardness of ash wood and the density of tested top layer floor elements, with top layer thickness 6.5, 4.0 and 2.0 mm, are presented on Figure 2. In all the cases, the coefficient of determination was high, but directional coefficient of straight lines is lower for the reduced top layer thickness, and lines are located below. This results from an increasing influence of the bottom layer made of pine wood, with lower density comparing to ash wood.

To minimize the influence of top layer density variations, samples were grouped into 20 buckets in such a way that samples with similar bottom layer density were put into the same bucket. This resulted in random top-layer densities and practically the same bottom layer densities in each bucket. Then, the mean of hardness and density values in each bucket was calculated. This should minimize the influence of varying top-layer densities on the results.

The correlations between the hardness of two layer-floor elements and the density of the bottom layer made of pine wood, while the top layer made of ash wood had different thickness, are presented in Figures 3, 4 and 5. For top layer thickness of 2.0 mm, the coefficient of determination $R^2 = 0,3512$ ($R = 0,59$) is high compared to the data sets concerning other top layer thicknesses.

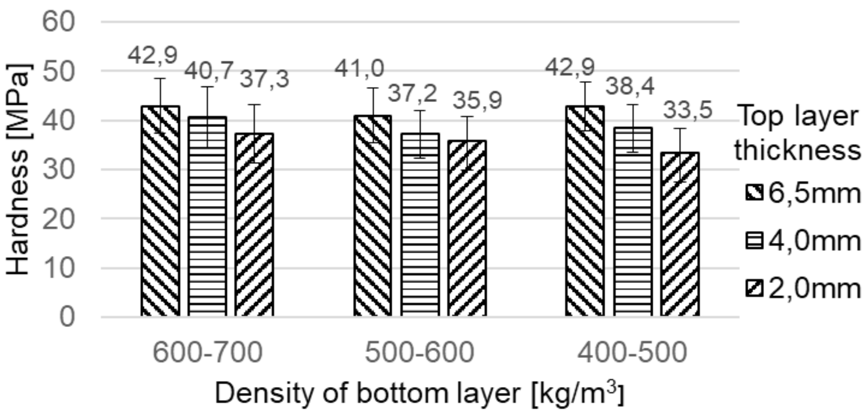

Fig. 1. Hardness of two-layer floor elements with different top layer thickness and bottom layer density: top layer made of ash wood, bottom layer made of pine wood

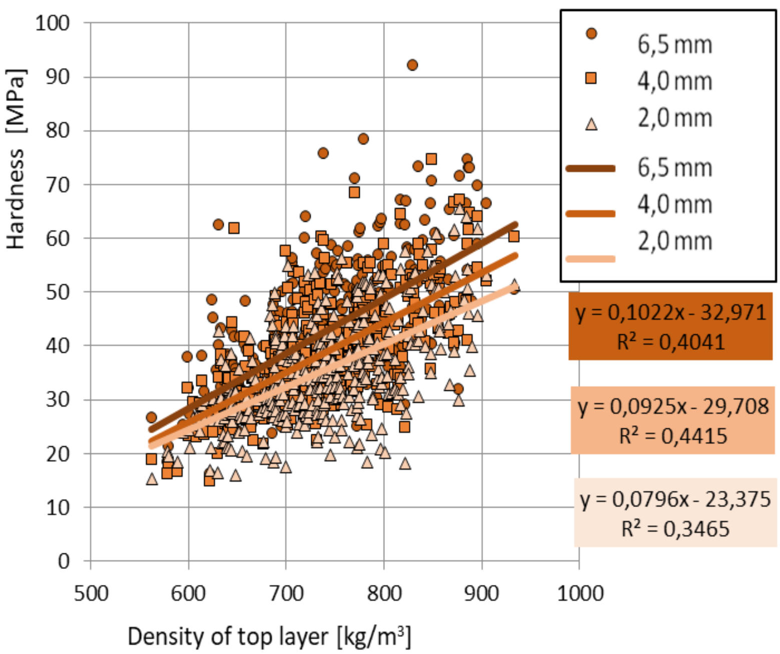

Fig. 2. Correlation between Brinell hardness of two-layer floor elements and density of top layer (top layer of different thickness)

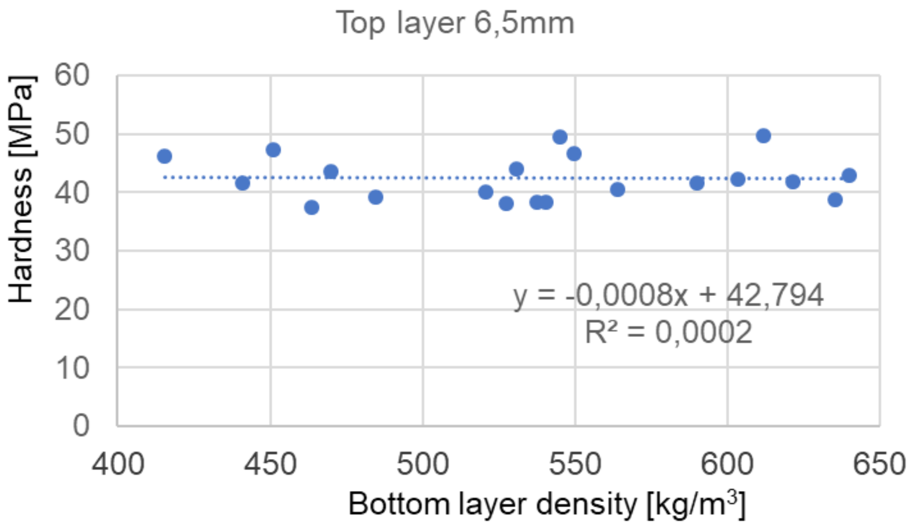

Fig. 3. Correlation between Brinell hardness of two-layer floor elements and density of bottom layer (top layer thickness 6.5 mm)

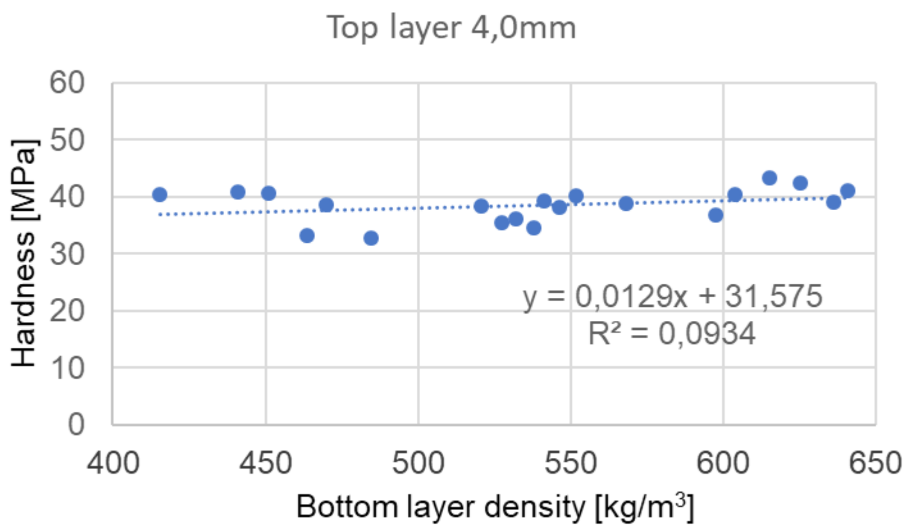

Fig. 4. Correlation between Brinell hardness of two-layer floor elements and density of bottom layer (top layer thickness 4.0 mm)

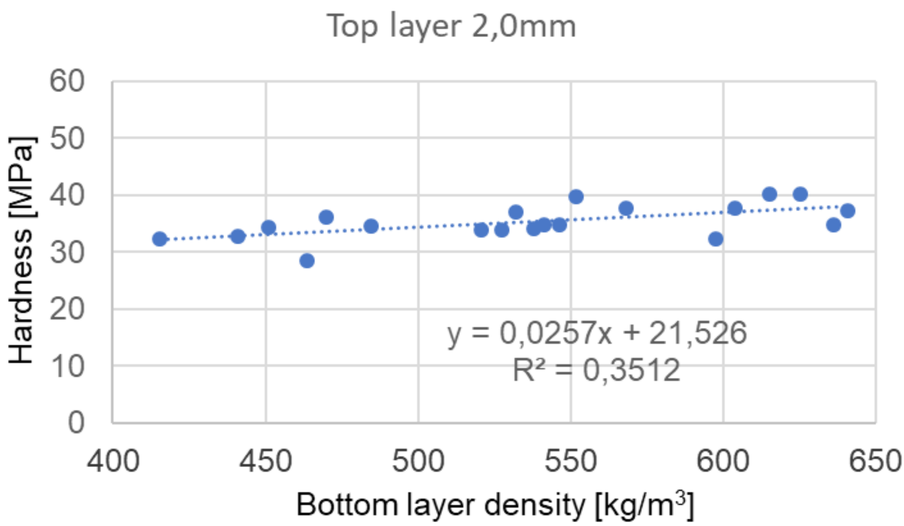

Fig. 5. Correlation between Brinell hardness of two-layer floor elements and density of bottom layer (top layer thickness 2.0 mm)

The results of cross-section analysis of two-layer elements in the zone of indentation after the hardness test are presented in figures 6, 7 and 8. In elements with lower hardness, higher compression and lasting deformations were observed in the top layer.

Fig. 6. Cross section of a two-layer (ash/pine) floor element.=

Top layer thickness 2mm and bottom layer thickness 24 mm. Element before hardness determination. Data regarding wood properties the same as in Figure 7].

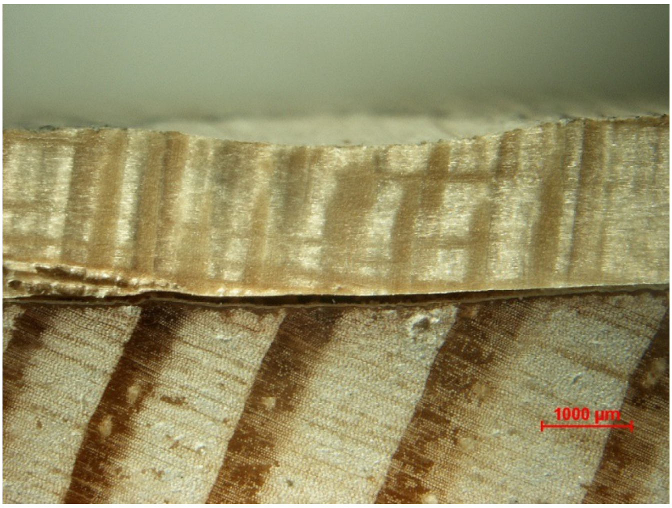

Fig. 7. Cross section of a two-layer (ash/pine) floor element after hardness determination in the zone of indentation

Initial top layer thickness was about 2 mm. Floor element hardness was 52.5 MPa. Bottom layer was made of pine wood with density 547 kg/m^3 and top layer was made of ash wood with density 830 kg/m^3. Delamination is visible in the indentation zone.

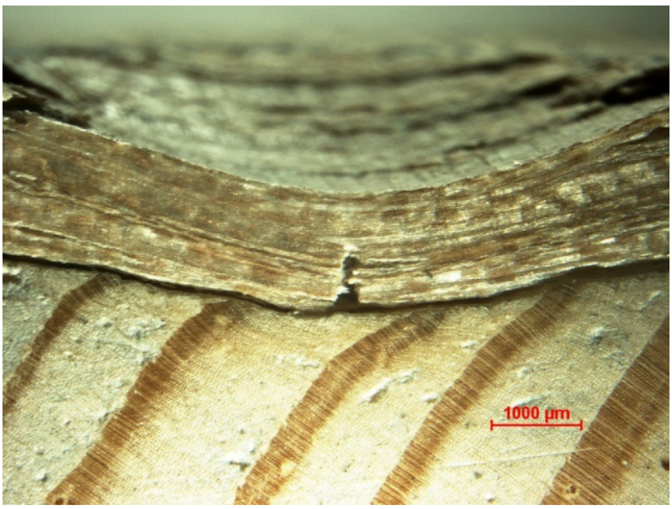

Fig. 8. Cross section of a two-layer floor element (ash/pine) after hardness determination in the zone of indentation

Top layer thickness was 2 mm. Floor element hardness was 34.7 MPa. Bottom layer was made of pine wood with density 412 kg/m^3 and top layer was made of ash wood with density 648 kg/m^3. Crack in the bottom of the top layer and deformations of rings in the bottom layer are visible.

Conclusions

On the basis of research and analysis of results regarding the hardness of two-layer floor materials with the top layer made of ash wood, tangential cut, and the bottom layer made of pine wood, radial cut, with cross wood fibre layout in both layers, the following conclusion were formulated:

1. The Brinell hardness of the top layer measured on longitudinal section of wood is characterized by high variation (coefficient of variation: 27.8%, 26.8% and 27.8% for top layer thickness of 6.5 mm, 4.0 mm and 2.0 mm, respectively) and was proportional to wood density.
2. In the case of top layer made of ash wood, 6.5 mm thick, the average Brinell hardness of two-layer floor elements is 42.4 MPa.
3. There is practically no influence of the bottom layer density on the hardness of two-layer floor elements in samples with top layer thickness of 6.5 mm and 4.0 mm.
4. Statistically significant influence of bottom layer density on the hardness of two-layer floor elements was observed in samples with top layer thickness of 2.0 mm.
5. During the hardness determination of two-layer floor elements, indentations appeared in the bottom layer made of pine wood in samples whose top layer was 2.0 mm thick.

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List of standards

ISO 13061-1:2014-10 Physical and mechanical properties of wood – Test methods for small clear wood specimens. Part 1: Determination of moisture content for physical and mechanical tests
ISO 13061-2:2014-10 Physical and mechanical properties of wood – Test methods for small clear wood specimens. Part 2: Determination of density for physical and mechanical tests
EN 1534:2000 Wood and parquet flooring – Determination of resistance to indentation (Brinell) – Test method
EN 1534:2011 Wood flooring - Determination of resistance to indentation - Test method
EN 13489:2002 Wood flooring. Multi-layer parquet elements

Acknowledgements

The authors are grateful for the support of the National Centre for Research and Development, Poland, under "Environment, agriculture and forestry" – BIOSTRATEG strategic R&D program, agreement No BIOSTRATEG2/ 298950/1/NCBR/2016.

Submission date: 19.03.2019

Online publication date: 15.05.2020