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ORIGINAL

Beech wood (*Fagus sylvatica* L.) flooring structures designed to increase the basketball bounce height

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Abstract

The present paper investigates the performance of eight different structures of beech wood (*Fagus sylvatica* L.) floorings designed for indoor basketball game court. Floorboard strips with the same lengths and widths and different thicknesses of 20 mm and 15 mm, respectively, were used to build the tested flooring structures. Joists and noggins with the same sizes and half lap jointed form the support construction mounted on the foundation. The same construction of sports floorings was applied to both categories of floorboard strips. Four variants of each category were tested. They were different through the material and position of the shock pads placed at the contact with the foundation. These variables were set in the experiment in order to improve the basketball bounce height. The tests were carried out according to SR EN 12235 standard. The best bounce heights were recorded for structures with floorboard strips of 20 mm thickness, provided with wooden shock pads placed at the half distance between the joists and noggins joints. For thinner floorboard strips, the rubber shock pads proved to be more efficient when positioned under the half-lap joints.

1 Introduction

Ball games in a broad sense are very popular among the sporting areas in recent decades. Football and basketball games play an important role in the culture of many European countries. Whilst football is an outdoor sport, basketball is an indoor sport and requires a special indoor court with performing solid wood flooring. The floors have to perform with optimum elastic characteristics, so to ensure the players protection against injury and to give them the appropriate freedom of movement with the highest efficiency. For this purpose, the specialists are concerned to design and develop floor systems, which provide safety and high performance and help the athletes to achieve their best. Various materials are used nowadays to build solid wood floors, and the most common ones are oak wood species (*Quercus robur, Quercus petraea*) and beech wood (*Fagus sylvatica* L.). New species of wood, such as cork oak wood (*Quercus suber* L.) (Knapic et al. 2012), sugar palm (*Arengapinnata*) (Nuryawan et al. 2017), or *Eucalyptus globulus* (Sepliarsky et al. 2018) are tested by the researchers in the field in order to achieve the required mechanical and physical properties for floorings. However, the niche of sports floorings is very narrow on the market, and the scientific research on testing these new materials for sports court requirements is very poor.

According to official FIBA basketball rules (FIBA Central Board 2017), the basketballs have to be inflated to an air pressure such that, when they are dropped onto the playing floor from a height of approximately 1800 mm measured from the bottom of the ball, they will rebound to a height of between 1200 and 1400 mm, measured to the top of the ball. There are two solutions applied to build sports flooring: fixed and portable ones. The vertical ball behaviour of these types of floor has to fulfil the requirements of SR EN 12235:2014. According to this technical requirement, a standard basketball, which drops from a height of 1800 mm, has to have a relative rebound height of at least 90% of the rebound height on concrete.

Several researchers studied the behaviour of basketball rebound as a consequence of movement and shooting position of the player (Oba 2009; Njock-Libii 2012; Okubo and Hubbard 2013; Uchida et al. 2014). Vertical ball behaviour depending on the air pressure in it was studied on a solid floor (Bjelica et al. 2016), and both height and duration of

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the rebounds were measured in the conditions when the height of free fall was of 9 m.

Various floor surfaces subjected to impact loads and analysis methods for determining surface responses are the subject investigated by other researchers (Wang et al. 2014; Yukawa et al. 2014; Colino et al. 2017) with results related to mechanical properties. In the abovementioned literature, none of the studies made reference to the wood flooring structures and their influence upon the basketball repulsion, and this is the novelty of the present paper.

The objective of the present paper is to investigate the performance of beech wood flooring structures by varying the thickness of the floorboards, materials and positions of the shock pads, and to compare the basketball bounce height of these structures after performing tests according to SR EN 12235 (2014) standard.

2 Materials and methods

2.1 Materials

Beech wood (*Fagus sylvatica* L.) floorboard strips with length (L), width (W) and thickness (T) shown in Table 1 were arranged as seen in Figs. 1 and 2. Prior to processing, the wood was kiln-dried at a moisture content of 10%. The average density of the beech wood at 10% moisture content had a value of 675 kg/m^3. It is the mean value of the densities of ten samples, which were calculated as the ratio

Table 1 Characteristics of investigated sport flooring structures

Type	Floorboard strips		Joists/Noggins		Shock pads		
	L×W×T	Pcs	L×W×T	Pcs	L×W×T	Pcs	Material
D1b2	500×50×20 250×50×20	30 20	1040×40×20	5	60×40×10	10	Wood
D1c2					60×40×10	13	Wood
D1d2					40×40×10	10	Rubber
D1e2					40×40×10	13	Rubber
D2b2	500×50×15 250×50×15	30 20			60×40×10	10	Wood
D2c2					60×40×10	13	Wood
D2d2					40×40×10	10	Rubber
D2e2					40×40×10	13	Rubber

Pcs pieces, *L* length (mm), *W* width (mm), *T* thickness (mm)

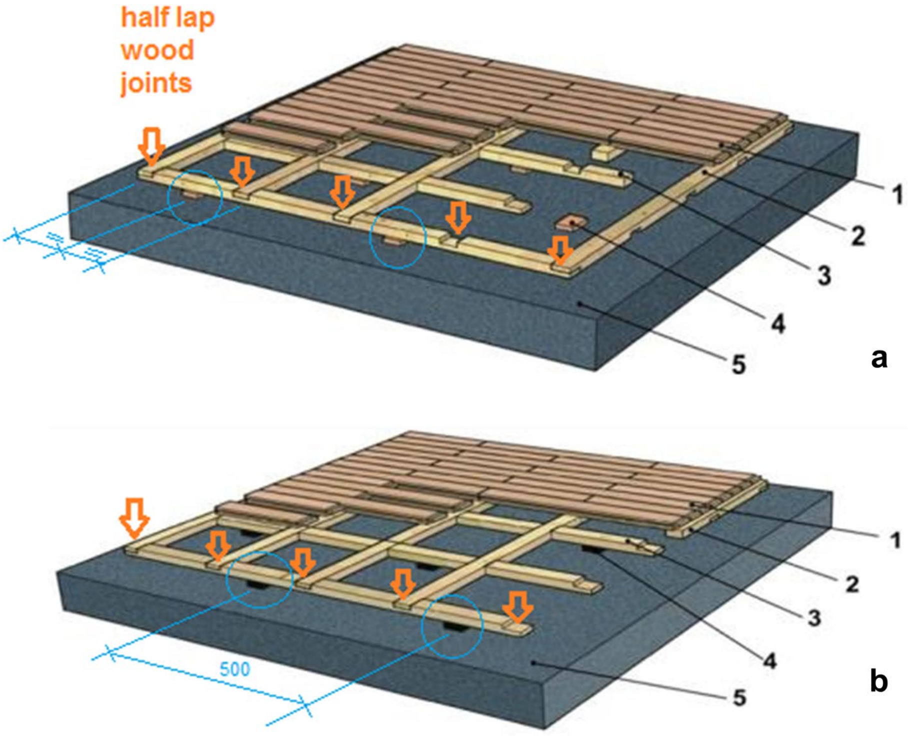


Fig. 1 Investigated structures of beech wood floorings with shock pads spaced at 500 mm and positioned at mid-distance between two half lap wood joints; **a** structures with wooden shock pads (D1b2, D2b2); **b** structures with rubber shock pads (D1d2, D2d2); 1—floorboards, 2—joists, 3—noggins, 4—shock pads, 5—foundation

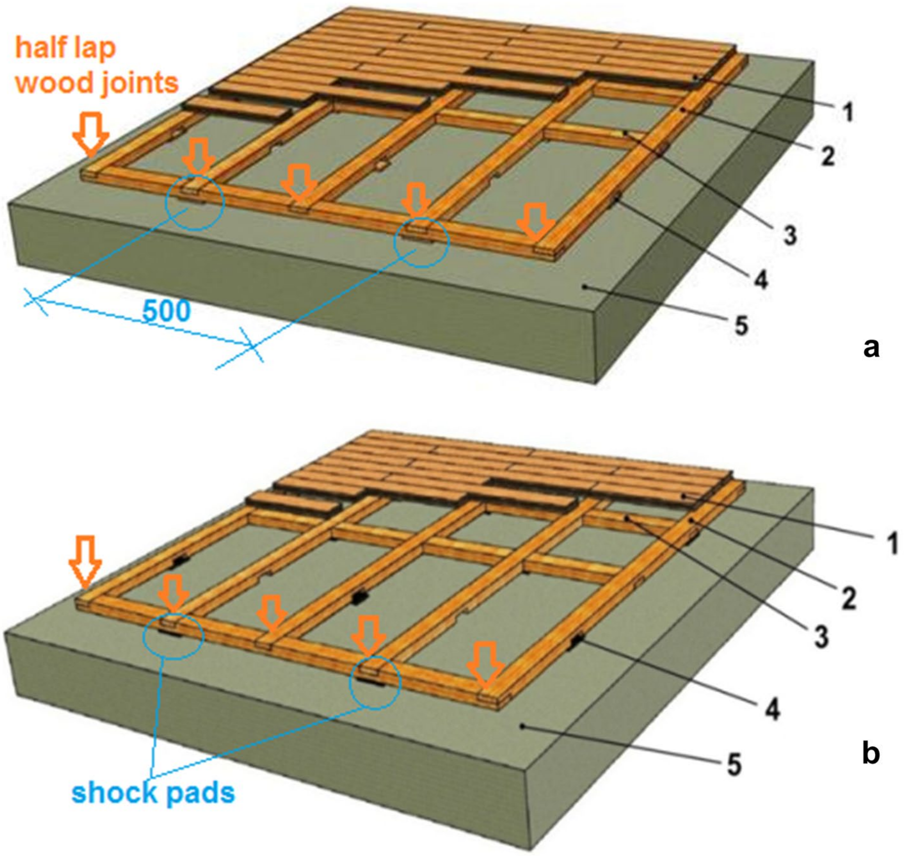


Fig. 2 Investigated structures of beech wood floorings with shock pads positioned under the joints; **a** structures with wooden shock pads (D1c2, D2c2); **b** structures with rubber shock pads (D1e2, D2e2); 1—floorboards, 2—joists, 3—noggins, 4—shock pads, 5—foundation

between their masses and volumes. Square floorboards with sizes of 1000 mm × 1000 mm were obtained in order to be tested according to SR EN 12235 (2014) standard for the determination of vertical ball behaviour. Joists and noggins made from beech wood and having sizes as shown in Table 1 were half lap-jointed in order to build the support construction of the floorboards. Five pieces of each type were placed at equal distances one to another and formed the support construction. Apart from the variation of the thickness of the floorboard strips (20 mm for D1 structures and 15 mm for D2 structures), two other variables were introduced in the experiment: material of shock pads (wood and rubber) and their position on the foundation, as seen in Figs. 1 and 2. The codification of the eight investigated structures and their characteristics are presented in Table 1.

The floorboard strips were glued by adhesive JOWACOL®103.05 and attached to the support construction. Screws with dimensions of Ø 3.5 mm × 30 mm (for D2 structures), Ø 4.5 mm × 30 mm (for D1 structures) and Ø 6 mm × 65 mm were used to join together the wooden flooring structures and the foundation.

The foundation was built as follows: a layer of reinforced concrete, above it a quick primer for non-absorbent substrates (BAUMIT Primer) was added and a final layer of 2–3 mm self-levelling floor screed (Nivello Duo from BAUMIT) ensured the flatness of the structure.

The GF7 Molten Official FIBA category 7A basketball ball (size 7, manufactured by Molten Corporation) was used for testing the vertical behaviour of the ball according to SR EN 12235 (2014) standard. The ball was inflated to a pressure of 0.7 bar and had a circumference of 0.756 m and a weight of 0.605 kg.

2.2 Equipment and method

Equipment used for testing the vertical behaviour of the ball (Fig. 3) was designed and executed according to SR EN 12235 (2014) standard requirements, and was inspired by the Vertical Deltec Ball Rebound Tester, manufactured by Deltec Equipment, The Netherlands.

The ball-releasing device is situated at an initial height (H_i) of 1.80 ± 0.01 m. The ball is introduced in a ring and it is pressed in three points, two of them with fixed positions and one of them provided with mechanical retraction. The height of the rebound ball was measured by an ultrasonic measuring device (Distance Sensor DT020-1) and Multi LogPro acquisition system. The digital tablet attached to the system provided the data collection, display and analysis

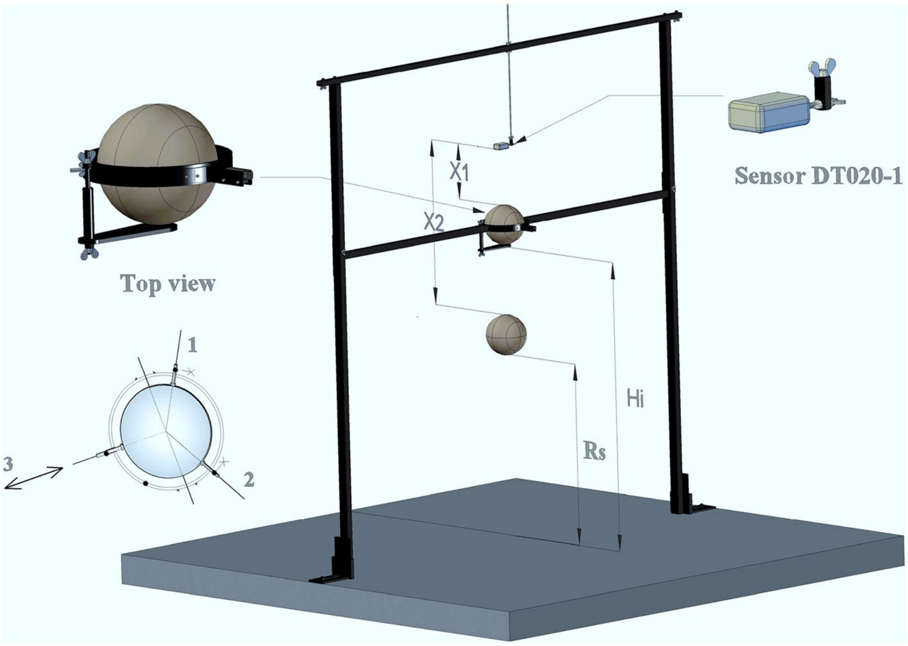


Fig. 3 Equipment used for testing the vertical behaviour of the ball

of data, transforming the movements of the ball into relevant graphical representations.

The basketball repulsion (R) on the tested floors is calculated, in %, by Eq. (1).

$$R\% = \frac{R_s}{R_c} \cdot 100 \tag{1}$$

where R_s is the bounce height measured on the surface of the floor in m, and R_c is the bounce height measured on the standard concrete floor, in m.

The repulsion height on the wooden floor was measured on nine points (Fig. 4). Point 1 is located above the half-lap joint, in the central point of the deck. Four points are located above joists and noggins, at equal distances between half-lap joints. The other four points are located above the central positions of the openings between joists and noggins. Five measurements for each point were taken. The final result is the mean value of all measurements. The reference value height (R_c) corresponding to the bounce height measured on concrete floor was of 1.204 m. R%—value has to be at least 90% of the reference value height according to SR EN 12235 (2014), which corresponds to the target height of 1.083 m.

Before performing the tests, the samples were acclimatized for 3 h at the test temperature of (23 ± 2) °C and relative humidity of (50 ± 5) %.

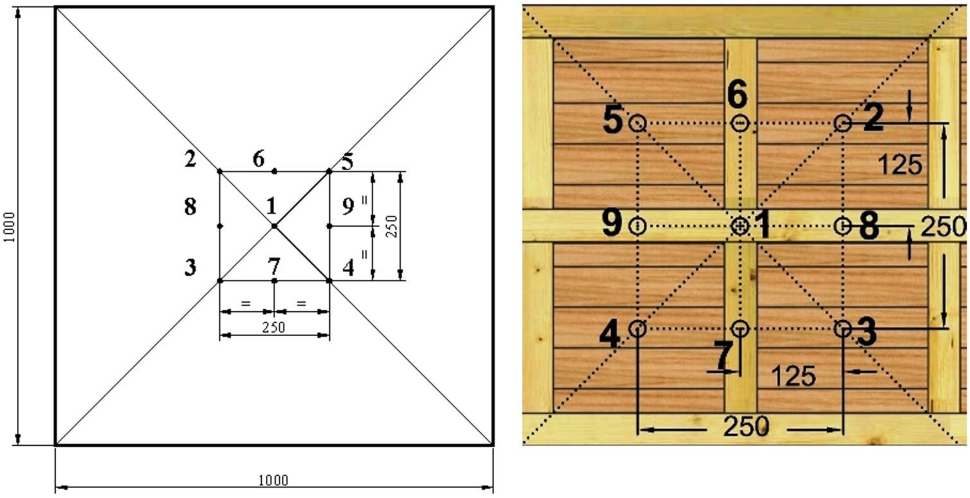


Fig. 4 The nine measuring points and their positions on the floor surface

3 Results and discussion

The mean values of bounce height (R_s) calculated for five measurements in the nine set points of the floor surfaces are presented in Fig. 5. The test results obtained for floorboards of 20 mm thickness (D1 structures) are presented on the left side of the graph. The test results of floorboards of 15 mm thickness (D2 structures) are presented on the right side of the graph. As can be noticed, the results are more uniform for D1 structures and the majority of measured bounce heights exceeded the target value of 1.083 m. In this case, when the shock pads were positioned between the half-lap joints, the best results were obtained for wooden shock pads (D1b2). The lowest bounce heights were obtained for structure D1c2. In this case, the shock pads are made from wood and they are positioned under the half-lap joints.

For the second case (structures D2), the best results were recorded for D2e2 structure. In this case, the shock pads are positioned under the half-lap joints and they are made from rubber. When replacing the rubber pads with the wooden shock pads (structure D2c2), the lowest values of the bounce heights were recorded, all of them being below the target height. In this case, both structures with rubber shock pads behaved better than those with wooden ones.

For a clearer image of the results, the symmetric points were grouped and the mean value of the bounce heights obtained for the points in the same group were calculated and used to build the graph in Fig. 6. As seen in Fig. 6, there are two groups of measuring points with same positions. The first group (group 1) is composed of points 2, 3, 4 and 5, and they are placed at the intersection of the diagonals of a frame mesh. The other group (group 2) is composed of measuring points 6, 7, 8 and 9 and they are placed at the mid-distance points between two consecutive half lap wood joints of the wood frame. It is assumed that the measuring points of the same group should have the same behaviour. The diagram in Fig. 5 shows differences between the measuring points of

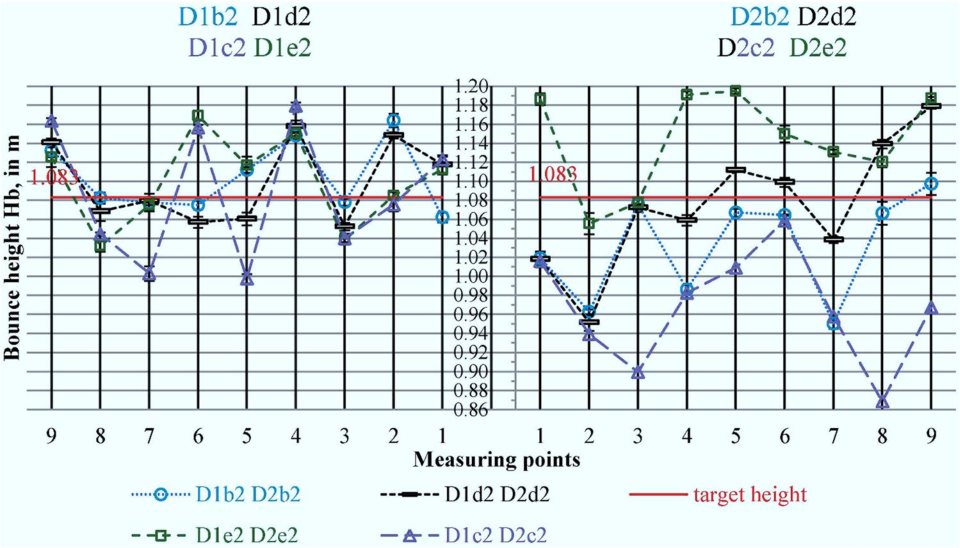


Fig. 5 Bounce heights measured in nine points of the investigated sports floorings

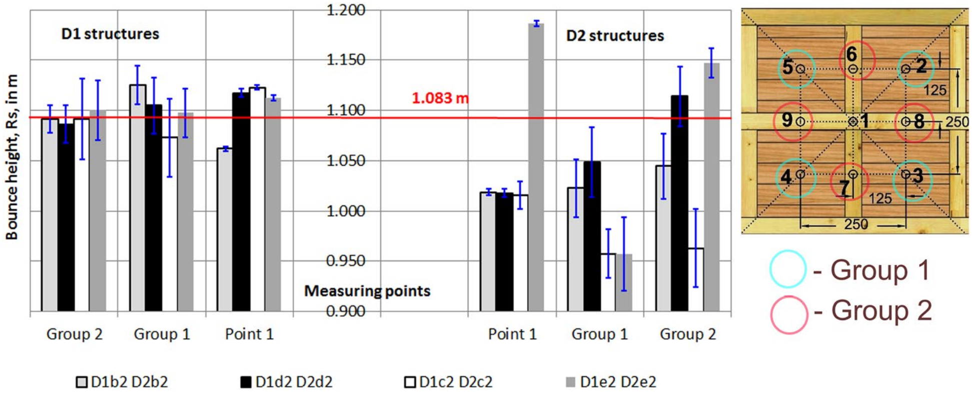


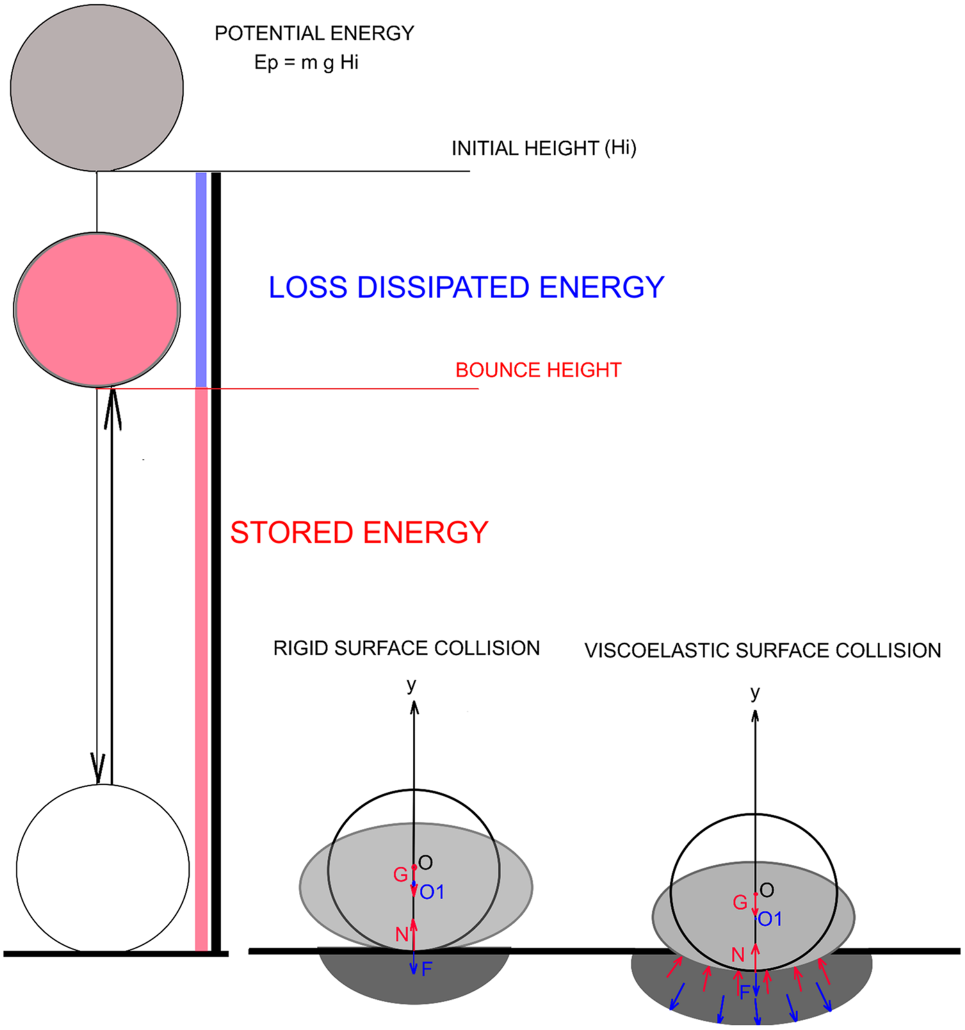
Fig. 6 Bounce height of the ball for group 1 (points 2, 3, 4, 5) and group 2 (points 6, 7, 8, 9) of symmetric measuring points and for point 1

the same group and of the same structure. The explanation is related to the anisotropic nature and non-homogeneous structure of wood on the one hand, and the cutting direction of wood, on the other hand. Even if points in group 1 and group 2 have symmetrical positions in relation to the central point of the structures (point 1), they are situated on different wood strips that don't have identical macroscopic structures, densities or wood cutting directions (radial, half-radial or tangential to the annual rings). In this case, the elastic behaviour of the wood strips are different and the response of the ball at the impact with the floor is also different and unpredictable for the points in the same group, as shown by the graph in Fig. 5 and by the standard deviations (calculated for the values of symmetrical points in the same group) from Fig. 6.

As seen in Fig. 6, measuring points in group 2 are positioned on the floor strips above the joists and noggins of the support frame, where a more rigid zone is conferred to the floor. In contrast, measuring points in group 1 are placed on the more elastic zones of the floor, at the centre of the mesh. Bounce height of the ball for the floor with 20 mm thick support frame (D1 structures) exceeds the limit of 1.083 m for measuring points in group 2 and has maximum values in point 1. In both cases, these points are placed on rigid areas. The same trend was observed for D2 structures, but lower performance of the ball was generally noticed, whereas the thinner floor strips subjected to strains have a higher elasticity. Bouncing behaviour of the ball may be explained by an energetic analysis (Rawol 2017). When the ball is dropped from a height (H_i), initial potential energy is $Ep = m\ g\ Hi$, where *m* is the weight of the ball, and *g* is acceleration due to gravity.

The initial potential energy (Fig. 7) is converted into stored energy and loss dissipated energy. Loss dissipated energy is found in the environment as sound energy, heat energy, and as friction forces from the collision of the ball with the floor. Additional, a part of energy is dissipated from vibrating floor slabs due to ball-floor impact interaction; a fact which was proved by the measurement

Fig. 7 Bouncing behaviour of the basketball on rigid and viscoelastic materials of the floor



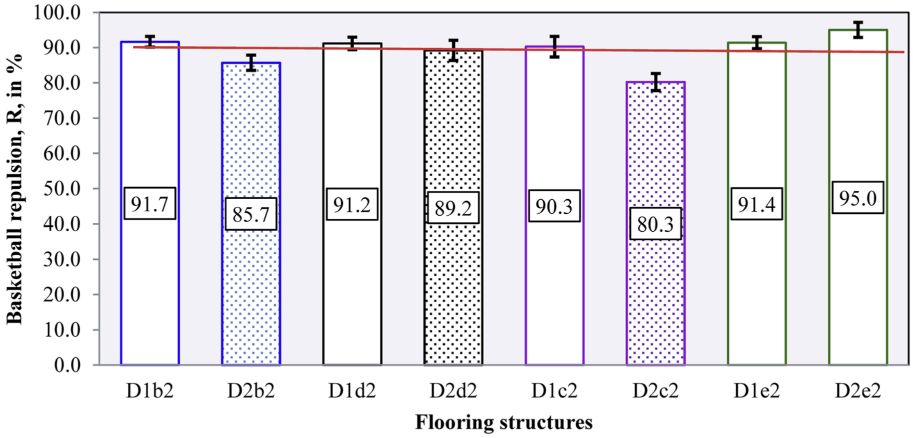


Fig. 8 Basketball average repulsion height measured for all tested flooring structures

of the damping coefficient of a falling rubber ball on a lightweight floor construction (Homb 2000).

In case of collision of a ball with a rigid surface of the floor, the ball will deform during the impact, as seen in Fig. 7. The center of mass tries to keep going, but the floor surface tries to stop it. This leads to both elastic deformation of the ball and the floor surface and to the occurence of insignificant friction forces inside the ball. Thus, a small part of the energy is dissipated as friction energy. The amount of friction energy depends both on the compression of the air inside the ball and the size of the contact surface between the ball and the floor. Although there is no lateral displacement of the ball on the floor, theoretically small friction forces occur due to the deformation of the ball at the contact with the floor, which ranges from a punctiform contact to a surface contact area, depending on the nature of the material. The contact surface between the ball and the floor is smaller in case of rigid materials compared to viscoelastic materials.

In the case of the experiment presented in this paper, wood floors behave as anisotropic viscoelastic material. In the condition where the air compression inside the ball is constant, the combination between friction forces and elastic “push-up” forces of the floor gives a particular restitution energy after the impact, which translates into bounce height of the ball. For more rigid parts of the floor (i.e. point 1 of D1 structures, D1c2 structure), the dissipated friction energy is lower and the ball becomes bouncier. D2 structures are composed of thinner floor straps compared to D1 structures, so they are more elastic. Performance wise the results of these structures for the measurement points of group 1 (points 2, 3, 4 and 5) are the lowest and show that dissipated friction energy exceeds the elastic stored energy of the floor, but for the more rigid areas like point 1 or group 2 of measuring points and adding rubber shock pads, the elastic stored energy of the floor proved to be higher than the dissipated one (structure D2e2). The large range of variation of ball response in the symmetrical measuring points and for the same structure also depends on the non-homogeneous structure of wood and its anisotropic elastic properties.

The mean values of the bounce heights calculated for the nine points of each structure were afterward used to calculate the basketball repulsion with Eq. (1). The results are shown in the diagram in Fig. 8 and are compared with the minimum value imposed by the SR EN 12235 (2014) standard, namely 90% of the reference height measured on the concrete floor. As seen in the diagram, all structures D1 met the requirements of the standard mentioned above, and the highest performance was recorded by D1b2 with wooden shock pads positioned between half-lap joints.

For structures D2, only that provided with rubber shock pads positioned under the half-lap joints met the requirements imposed by SR EN 12235 (2014) standard.

Even if structures D2e2 recorded the best values, as shown by Fig. 8, there are areas on D2 structures with low performances (D2b2, D2c2). The overall good results belong to D1 structures with floor strips of 20 mm thickness, and the best one is D1b2 with wooden shock pads positioned between half-lap joints. This structure provides the best equilibrium between the elastic stored energy and loss dissipated energy, so to ensure a satisfactory bounce height of the ball.

4 Conclusion

The results of the research show that structures having thicker floorboards increase the basketball bounce height. For the case where the thickness is 20 mm, the structures with wooden shock pads positioned between joists and noggins half-lap joints are preferred, having a basketball repulsion of 91.7%, exceeding the minimum limit of 90% imposed by SR EN 12235 (2014). For thinner floorboards, the structures with rubber shock pads are preferred, due to the fact that these structures fulfil the requirements of SR EN 12235 (2014) standard. For the case where the thickness is 15 mm, the shock pads have to be positioned under the half-lap joints, but the bounce height of the ball does not fulfil the requirements of SR EN 12235 (2014) standard for all the areas of the floor.

As the research results show, the points where the bounce heights are higher are positioned either above the central points of the openings of the support construction or above the mid-points positioned between the half-lap joints.

Structures with floor strips of 20 mm thickness and wooden shock pads positioned between half-lap joints are recommended for the construction of sports hall floorings, having the performance required by SR EN 12235 (2014) standard. This performance is the result of the equilibrium between the elastic stored energy and loss dissipated energy related to friction forces between the ball and the floor. The large variation of the results for symmetrical measuring points is explained by the non-homogeneous structure of wood and its anisotropic elastic properties, due to the fact that the floor strips are not identically cut from the logs and their macroscopic structure depends on their place of origin from the wood log.

The cases analysed in this paper provided only solutions where two and three shock pads were alternatively positioned on the noggins. Further research has to be performed on structures with an increased number of shock pads and also on thicker floorboards.

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