Domagoj Mamić, Danijela Domljan[1]

Positive Aspects of Using Solid Wood in Interiors on Human Wellbeing: A Review

Pozitivni aspekti primjene masivnog drva u interijerima na dobrobit ljudi – pregled literature

REVIEW PAPER
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ABSTRACT • *The paper provides an overview of research conducted in the field of wood application in the interior environment and on how solid wood as a material affects human behavior and sense of wellbeing. The analyzed literature includes articles published in the period 1989-2021 in Pub-Med, Google Scholar, Scopus, and Web of Science (WoS) databases using keywords: wood; wellbeing; psychological and physiological responses; indoor environment. Thirty-one articles were processed. Results from the studies confirmed that people have a strong connection and positive behavioral reactions in relation to the use of solid wood in interiors. Wood visually and tactilely affects the mental state of users, and affects physical state, productivity, and stress. Selected studies were reviewed to better understand the impact of the solid wood application on user behavior, health, and wellbeing using objective and subjective test methods. All the findings can be a potential guide for greater future implementation of wood in the sustainable interior design of timber buildings by wood processors, manufacturers, architects, and interior designers, as well as a more vital branding of sustainable and healthy wooden products and buildings with the aim of increasing the wellbeing in interior environments with an emphasis on furnishing sustainable public facilities.*

KEYWORDS: *solid wood in interior, sustainable environment, wood product design, user behavior, wellbeing*

SAŽETAK • *Rad donosi pregled istraživanja provedenih na području primjene drva u interijeru te utjecaja masivnog drva kao materijala na ljudsko ponašanje i osjećaj ugode. Analizirana literatura obuhvatila je članke objavljene u razdoblju 1989. – 2021. u bazama podataka Pub-Med, Google Scholar, Scopus i Web of Science (WoS), a pretražene su korištenjem ključnih riječi: drvo, blagostanje, psihološke i fiziološke reakcije, unutarnje okruženje. Obrađen je trideset i jedan članak. Rezultati istraživanja potvrdili su da ljudi osjećaju snažnu povezanost s masivnim drvom u interijeru i pozitivno reagiraju na njegovu primjenu. Drvo vizualno i taktilno utječe na psihičko stanje korisnika, na njihovo fizičko stanje te na produktivnost i stres. Odabrane su studije pregledane primjenom objektivnih i subjektivnih metoda ispitivanja kako bi se bolje razumio utjecaj upotrebe masivnog drva na ponašanje, zdravlje i dobrobit korisnika. Sva otkrića mogu biti potencijalni vodič za opsežniju buduću primjenu drva u održivom dizajnu interijera drvenih zgrada, na što uvelike mogu utjecati prerađivači drva, proizvođači, arhitekti*

[1] Authors are PhD student and Associate Professor at University of Zagreb, Faculty of Forestry and Wood Technology, Zagreb, Croatia. https://orcid.org/0000-0002-6388-5825

i dizajneri interijera, kao i aktivnije brendiranje održivih i zdravih drvenih proizvoda i zgrada radi povećanja dobrobiti u interijerima, s naglaskom na opremanje održivih javnih objekata.

KLJUČNE RIJEČI: *masivno drvo u interijeru, održivi okoliš, dizajn proizvoda od drva, ponašanje korisnika, dobrobit*

1 INTRODUCTION
1. UVOD

A vast majority of the population today spends more time indoors (Allen and Macomber, 2020), mostly at home and at the workplace and in other public spaces such as restaurants, schools, shopping centers, office spaces, public institutions and other interiors (Kosonen and Tan, 2004; Höppe, 2002). COVID-19 pandemic has profoundly changed people's ability to recreate outdoors, keeping most of them indoors (Dzhambov *et al*., 2021).

Spaces significantly influence human behavior and feelings, and thus the feeling of wellbeing and health. The results of many studies prove that symbiosis with natural, biophilic design and wood is closely related to better mental and physical health, and contributes to the wellbeing of the individual (Wilson, 2003). Historically, wood has always been used as a traditional building material, but the impact of wood on human wellbeing in interiors is only beginning to be taken seriously and has been researched more intensively in recent decades (Ritter *et al*., 2011).

A number of designers and architects state that the feeling of nature and warmth is the reason why they use wood as the main material in their works, and many will agree that wood is visually more pleasant and calming than other materials (Kaplan and Kaplan, 1989; Fell, 2010).

Despite the claim that wood is one of the preferred natural materials in interiors, there is not much data and research on how wood as a material affects the cognitive perception and behavior of users in interiors, which would provide guidelines for the design of defined products from the appropriate type of wood - not only from a technological but also a visually cognitive point of view.

The aim of this review is to contribute to unifying the knowledge of previous researchers who have investigated the influence of wood in interiors through different products (floors, ceilings and walls) and the influencing parameters of wood on human behavior in interiors. The goal is to enable further research into the impact of certain wood products (e.g., wooden panels) and certain types of solid wood (e.g., oak), the new design which would improve the user's perception of the environment, health, and sense of wellbeing when staying in public spaces.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The paper follows the structure of a literature review according to the approach of Grant and Booth (2009), which includes three main steps: i) a comprehensive literature search; ii) synthesizing the material in a narrative form; iii) analysis of the paper's contribution in a thematic way. In order to accurately and reliably summarize the evidence, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement is used for reporting systematic reviews (Liberati *et al*., 2009), which helped in the correct methodological approach.

2.1 Search strategy
2.1. Strategija pretraživanja

A close connection between wood products and surfaces in the interior and their psychological and physiological impact on humans has been investigated through literature research and review.

The paper presents an original research obtained by searching articles published from 1989 to 2021 found on Google Scholar, Scopus, PubMed and Web of Science (WoS) online databases. The literature was collected in the period from December 2021 to July 2022, by using the list of keywords "wood"; "wellbeing"; "psychological responses"; "physiological responses"; "indoor environment"; "material properties" and similar terms and combinations related to wood and indoor environment. These terms are combined using the Boolean operators AND and OR (between key terms). Keywords and search combinations were "wood" AND "interior" OR "indoor environment"; "wood" AND "wellbeing" OR "psychological responses" OR "physiological responses"; "wood" AND "stress" OR "productivity".

An additional search of reference lists was manually conducted for the identification of additional, relevant studies, which resulted in finding a couple of articles that were not originally written in English but could also be found in one of the observed databases. To make comprehensive research in this field, relevant research reports, conference papers, books and doctoral dissertations have been included in the search as well.

2.2 Selection of studies
2.2. Odabir studija

In publication research, the main focus was on wood products used in the indoor environment such as

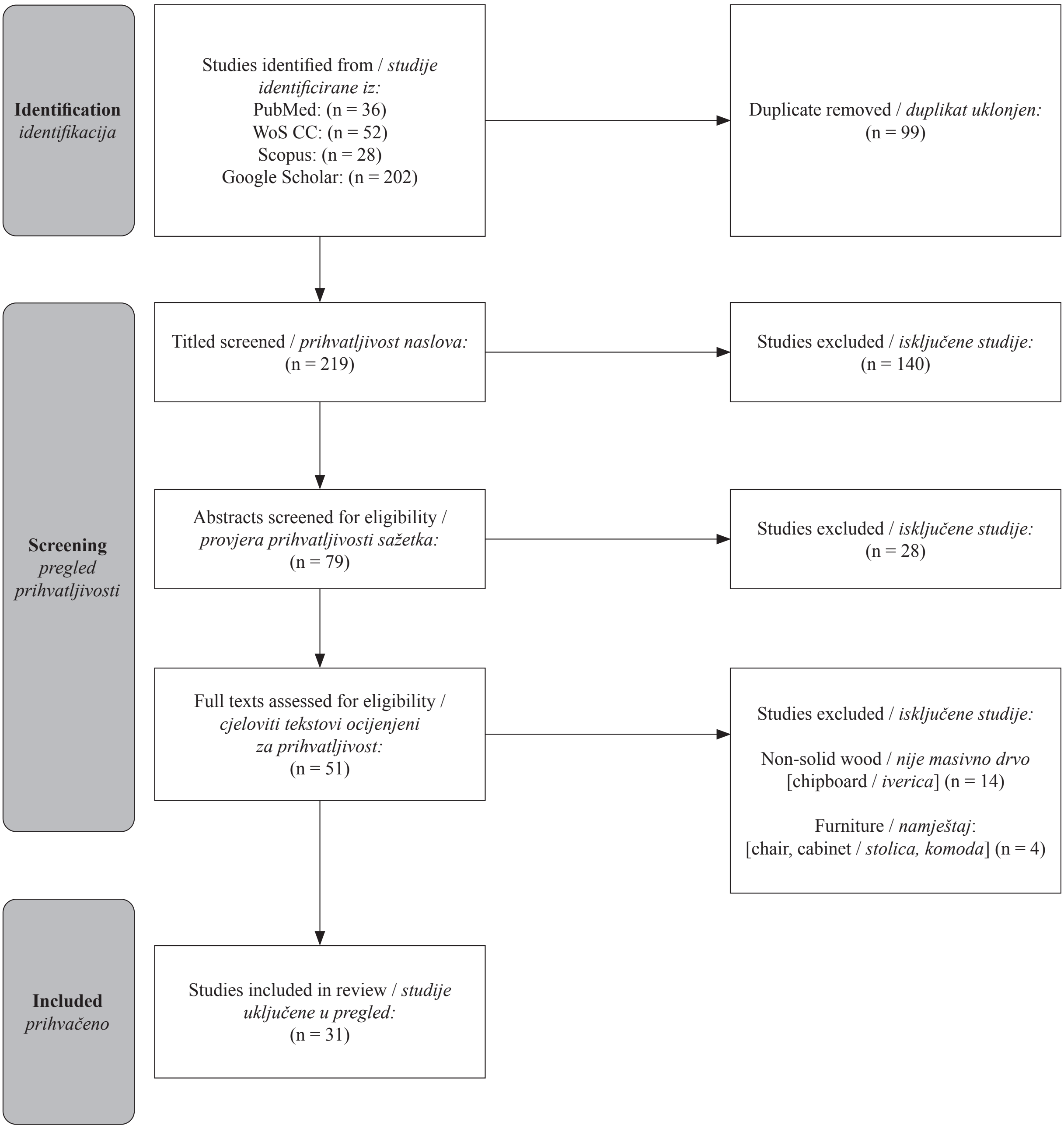

Figure 1 PRISMA-ScR flow diagram showing the process of selecting articles
Slika 1. PRISMA-ScR dijagram toka koji prikazuje proces odabira članaka

wall and ceiling paneling, solid wood surface material used in indoor applications such as veneers. Wood products such as chipboards and all wood based engineered products were eliminated because of their chemical (emissions of volatile organic compounds) and physical (visual appearance) properties, which are different from those of solid wood. Furthermore, the influence of wood furniture in the indoor environment was excluded as it was not within the scope of research.

After the primary results of search terms and addition investigation, 318 studies were chosen for further evaluation. Reading the articles, checking the quality of studies, and relevance of study topics, a total of 31 publications published between 1998-2019 were selected. The publications covered topics of air quality – humidity, antibacterial effects, productivity, stress relief, tactile and visual impacts of wood and wooden surfaces on human behavior.

Figure 1 presents a flow diagram adapted from PRISMA (Liberati *et al*., 2009) of the search process.

3 RESULTS
3. REZULTATI

The results obtained after the literature search were reviewed in detail, and for easier understanding of the cause and effect relationship, they are conceptually presented in Figure 2. The analyzed results imply a division into two groups, subjective and objective. These two groups of results together influence human

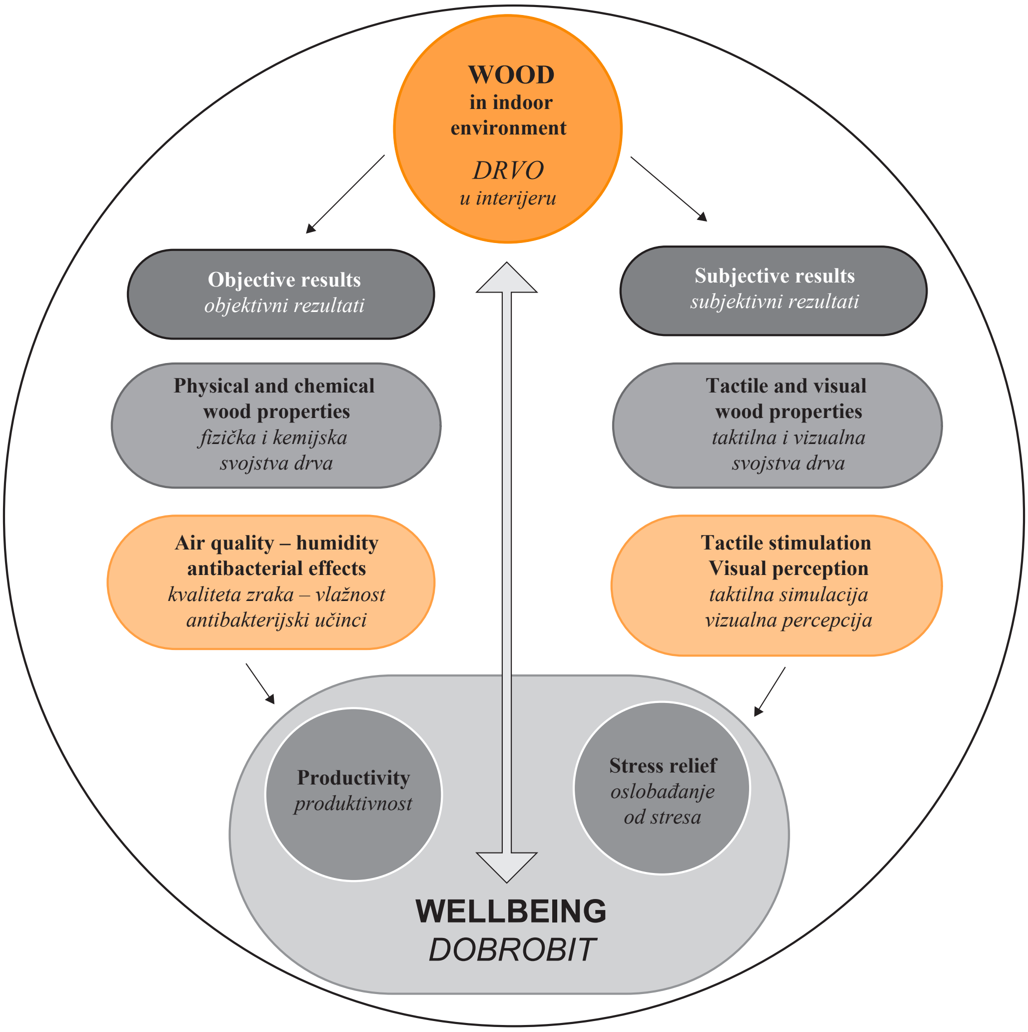

Figure 2 Mind map of identified relationships among results
Slika 2. Mentalna mapa identificiranih odnosa među rezultatima

behavior in terms of productivity and stress relief, which results in a positive outcome or wellbeing.

3.1 Objective results
3.1. Objektivni rezultati

These results are factual and independent, obtained by systematically measurable methods and are not prone to variations and other influences based on the physical and chemical properties of wood (Tsoumis, 1991). The results related to wood and its influence on humidity and air quality, as well as on antibacterial properties, were studied.

3.1.1 Air quality – humidity
3.1.1. Kvaliteta zraka – vlažnost

Wood is a hygroscopic material capable of absorbing and releasing water (Mortensen *et al*., 2005). Various studies have shown that the presence of wooden elements in the room can improve air quality by affecting the humidity of the room (Simpson, 1998; Hameury and Lundström, 2004**)**. When there is a higher amount of moisture in the room than in the wood, the wood will absorb excess water from the air, and also maintain the balance with the relative humidity in the surrounding air.

This characteristic of wood is a particularly important factor that affects the quality of workplaces. Productivity is reduced by 12 % in situations where employees are dissatisfied with the air quality in their workplaces (Bergs, 2002). Wooden products also increase the quality of life in residential areas because wood reduces the relative humidity in the living rooms and has a potential of up to 35 % compared to non-hydroscopic structure (Simonson *et al*., 2002).

Li *et al*. (2012) conducted a room-level test measuring the moisture buffering performance of wood wall coverings and their impact on the interior. The authors noted that wood is not the only material that lowers the moisture content of the air in the room and concluded that the room itself can cause up to 8 % change in relative humidity. Wooden wall coverings can mitigate this change by up to 30 %.

The absorption of wood moisture from the air depends on various factors such as the surface area of the wood exposed to the air from the interior, vapor permeability, surface treatment, thickness and sorption capacity (Osanyintola and Simonson, 2006).

3.1.2 Antibacterial effects
3.1.2. Antibakterijski efekti

With various well-known characteristics of wood such as the previously mentioned ability to bind moisture, scientists are becoming increasingly interested in the antibacterial properties of wood. So far, it has been discovered that wood repels bacteria better than plastic or glass (Hedge, 2015).

Kotradyova and co-authors (2019**)** performed microbiological testing on oak and pine in three different surface treatments (on a wooden surface without finishing, on acrylic varnish, and on a hard-wax oil finish). The results of the analysis showed the presence of antimicrobial action of wood, in contrast to the laminate used for comparison. More bacteria survived on wood treated with varnish than oil. Oak and pine have also been shown to have higher antimicrobial activity even without any chemical treatment because of the presence of tannins and terpenoids.

Another similar study was conducted by Vainio-Kaila and co-authors (2017), who compared the survival of bacteria on untreated wooden surfaces and glass surfaces. Bacteria such as *Escherichia coli* and *Listeria bacteria* were grown in the laboratory and died completely on wooden surfaces during the test, while surviving on glass plates. It has been found that wood is effective in fighting hospital bacteria. Wood contains various extracts that are characterized by their antibacterial properties.

Not every wood species has the same antibacterial properties. This depends on the species of wood. Sapwood and hardwood have different antibacterial properties within each species (Kavian-Jahromi *et al*., 2015). Extremely strong antibacterial effects have been found in Scots pine wood (*Pinus sylvestris*) (Vainio-Kaila *et al*., 2017, Schönwälder *et al.*, 2002; Milling *et al*., 2005; Laireiter *et al.*, 2013) and European oak wood (*Quercus robur*) (Milling *et al*., 2005). The back of a larch wood (*Larix decidua*) also showed antibacterial properties (Laireiter *et al*., 2013).

3.2 Subjective results
3.2. Subjektivni rezultati

These results were obtained by subjective methods (survey questionnaire, interview and observation), but also by measuring heart rate and blood pressure. The results show the impressions, opinions, feelings and attitudes of users towards wood, which is viewed from the side of visual perception and tactile stimulus.

3.2.1 Visual perception
3.2.1. Vizualna percepcija

The visual impression of wood can vary due to various factors such as species, number of knots, color, structure and surface finish. Examining the visual perception of wood can provide insight into how people perceive different properties of wood. Wood species most often differ based on the visual perception of wood characteristics such as the difference between dark wood and light wood. Likewise, adjectives like exclusive, modern, and inexpensive are used to indicate differences in wood species. Some of the most commonly used factors when describing wood are exclusive – modern vs inexpensive, ecofriendly – natural, and dark – rough. Research has shown that hardwood floors are more often perceived as more expensive and exclusive, while softwoods are considered more environmentally friendly than hardwood (Roos *et al.*, 2013). There are two components that play a major role in the separation of different wooden decking materials (Nyrud *et al.*, 2008). The first component includes unevenness, roughness and knots in relation to flat surfaces, and the second component is the degree of whiteness.

Bowe and Bumgardner (2004) concluded that darker-colored wood is perceived as more expensive than lighter-colored wood. According to Roos and colleagues (2013), this thesis was partly confirmed since their study showed that the results of Nyrud and co-authors (2008) were correct in stating that exclusivity and great value can be perceived both in light wood (maple) and dark wood (ash, elm, and oak). A positive correlation was found in relation to the number of wooden elements in the room, in such a way that respondents perceive rooms as warmer if there is more wood in them (Masuda, 2004). The feeling of warmth in the room was related to the color of the wood, where the colors from the yellow-red spectrum dominated. However, an environment with a high percentage of wood is perceived in more cases as a "natural environment" than a "warm environment".

According to Nakamura and Kondo (2008), knots on wood are a proof that they came from a living tree, which can give the wood used in the interior a more natural look. Knots can also present difficulties in terms of reducing the mechanical strength of wood, which is why too many knots are still undesirable in wooden materials (Broman*,* 2001). Therefore, sawn wood with few knots is sold at higher prices as opposed to that with more knots. Broman (2001) argues that there is a difference in the way people perceive wood materials with knots compared to those without knots. It was proved that the number of knots negatively affects customer preferences. Nakamura and Kondo (2007; 2008) investigated why knots are often perceived as a poor visual feature of a wooden surface. Their research results (Nakamura and Kondo, 2007) showed that there is a linear relationship between subjective visibility and the number of knots and concluded that participants were more relaxed when looking at clean surface wood than the one with knots.

Coherence is another important property of the visual quality of wood. Coherence defines the unity of a material and can be changed and improved by repeating texture and color patterns (Tveit *et al*., 2006). Several studies have shown that coherent or visually harmonious surfaces are important for preferences (Broman, 1995a; Broman, 1995b; Broman, 1996; Broman, 2001; Nyrud *et al.*, 2008). It has been observed that people prefer surfaces with a homogeneous texture that provide the experience of the whole (Kaplan and Kaplan, 1989).

Nakamura *et al.* (2019) conducted two types of psychological measurements (Semantic Differential (SD) and Profile of Mood State (POMS 2)), where subjects were shown two virtual square images of a wooden wall, where the direction of the wood was turned vertically on one side, and on the other horizontally. The interpretation of the results of the SD method on the vertically displayed image of a wooden wall showed a higher level of relaxation among the participants and significantly lower tension and anxiety. In the POMS 2 test, the vertical image had better results on the "strength, activity and friendship" scale. This research suggests that visual stimulation depends on the direction, i.e. the horizontal and vertical position of wooden elements in the interior.

An interesting study was conducted in hospitals, where the experience of the amount of installed wood in the interior was compared using questionnaires with employees (Nyrud *et al.*, 2014). Respondents were shown ten different images of hospital rooms of unique design. The difference was based and measured on the amount of wood in each of the hospital rooms, from a room without wood to a room covered entirely in wooden wall coverings. The results showed that the most desirable design of a hospital room was the one with medium wood use, while a room completely covered with wood paneling was the least desirable. This research has shown that, despite the fact that wood is a natural material, its application is limited and it should be carefully balanced in application and not overdone.

3.2.2 Tactile stimulation
3.2.2. Taktilna stimulacija

Several studies have proven that wood is used not only for furniture but also as a building material in the indoor environment that has a big impact on people's mood (Rice *et al*., 2006; Fleming *et al*. 2013; Lindberg *et al.,* 2013; Strobel and Nyrud, 2017). It makes people feel comfortable and relaxed not only visually, but also by touch. People react positively to wood because it creates a warm atmosphere.

Tactile research of wood has shown that wood has an advantage over other materials because it is characterized by various textures, and due to its constant temperature, it creates a feeling of comfort and security in people. This comparison was shown through the observation of the temperature of a metal handrail that varies depending on the seasons, being hot in summer and cold in winter, which is not the case with wooden handrails whose temperature is consistent throughout the year (Obata *et al.,* 2005).

Wang and colleagues (2000) studied the influence of tactile stimuli on physiological characteristics by comparing skin temperature in relation to the heat flux of the material. These two parameters are related because heat flux affects the thermal conductivity of a material in relation to the temperature difference between the skin and the material with which the skin is in contact. It was noted that wood has significantly lower thermal conductivity than other materials such as tile, marble and concrete. In a separate Finnish study, natural and smooth wooden surfaces were found to be more pleasant than those coated (Bhatta *et al*., 2017).

A similar study was conducted investigating the effect of tactile contact with wood on two indices of physiological stress responses: pulse rate and blood pressure (Morikawa *et al*., 1998). Two types of wood were used - Japanese cedar with a planed and sawn surface and Japanese cypress with a sawn surface. Other materials used in the research were trapper, silk, stainless steel plate and a vinyl bag filled with cold water. The results showed that the tactile experience with denim and stainless-steel plate resulted in a high rate of pulse fluctuation and systolic blood pressure, while the contact with wood caused a low rate of fluctuation.

A study conducted by Sakuragawa and co-authors (2008) examined the effects of tactile contact with various wood materials in relation to changes in blood pressure (the body's response to stress) and subjective evaluation of materials. Wooden samples used Japanese cedar wood, Japanese cypress, oak and urethane-coated oak. Other materials used were aluminum and plastic. The research showed the following: contact with the wooden samples caused the participants to feel comfortable and no increase in blood pressure was observed; contact with chilled wood caused uncomfortable but at the same time natural feeling in the participants, and no increase in blood pressure was observed; and contact with room temperature aluminum or chilled plastic led to artificial and uncomfortable sensations and an increase in blood pressure was observed. The authors concluded that the temperature of the material has a significant effect on increasing blood pressure, while wood, unlike artificial materials, did not cause a psychophysiological reaction to stress.

Tactile stimulation research by Ikei and colleagues (2017a) was conducted in such a way that the sensors for physiological measurements were placed on the forehead of the participants. Eighteen female students participated in the study, and the materials used were white oak, tile, marble, and stainless steel. The results turned out that the only natural material used (white oak) reduced activity in the prefrontal cortex, while other materials did not. A significant increase in parasympathetic nerve activity was also observed, which proves that tactile contact with wooden materials leads to physiological relaxation.

Another study by the same authors (Ikei, *et al.,* 2017b) aimed to examine the cause-and-effect relationships of touching wood samples with different coatings (uncoated wood, vitreous-finished wood, oil-finished wood, mirror-finished wood, urethane-finished wood) on left and right prefrontal cortex activity and autonomic nerve activity. The results showed that uncoated wood and wood treated with oil had the most positive effect on tactile stimulation. These measurements showed that parasympathetic activity increased while prefrontal cortex activity decreased. In other words, these results explain why wood has a physiologically relaxing effect on humans. Some explanations were based on the difference between warm-cold, dry-wet and flat-uneven. However, for "pleasant" and "relaxed" feelings, there was no significant difference in subjective assessment.

The tactile sensation of touching three different surfaces, oiled parquet, lacquered parquet and laminate flooring, was investigated in Austria (Berger *et al*., 2006). After participants tactilely explored the floors with their hands and feet, the results showed that a floor with a naturally oiled surface was perceived as warm, rough and quite soft. Laminate floors were perceived as cool, smooth and hard, and the experience of varnished parquet was quite cold, quite smooth and quite hard. The majority of respondents preferred flooring with a natural oiled surface.

Wood is considered warmer in visual and tactile research compared to stone, plaster, and steel or stone (Wastiels *et al*., 2012). It is interesting to note that in the comparison of different types of wood, it is more difficult to make an estimate of heat, even tactilely (Fujisaki *et al*., 2015).

3.3 Wellbeing
3.3. Dobrobit

Findings from the literature show that the properties of wood affect human behavior in everyday situations. The connection between wood as a material used in the interior with productivity and stress was analyzed in order to find a potential connection to a sense of comfort and wellbeing.

3.3.1 Productivity
3.3.1. Produktivnost

The link between job satisfaction and productivity has been well established in several academic papers. The happier the worker, the more efficient he will be at work (Browning *et al*., 2012). Therefore, it is crucial for organizations to focus on worker satisfaction in order to maximize productivity (Westover *et al*., 2010). Wood in interior design is being increasingly used to achieve diversity in design styles. The use of wood in the interior can make the atmosphere of space from informal, rustic, contemporary to elegant and sophisticated. Nowadays, there is an increasing trend of biophilic design that can be seen in various places such as restaurants, offices, classrooms, and universities (Xue *et al*., 2019). Research has shown that there is a correlation between wood in the interior and productivity. This can be seen in the results that describe reduced stress levels, better cognitive functions, greater creativity and general wellbeing of respondents while staying in rooms equipped with a variety of wooden details. In the design of offices and other workplaces, the role of wood is of great importance as it can improve employees satisfaction and productivity in their workspace (Fell, 2010).

Knox and Parry-Husbands (2018) investigated the existence of a connection between nature, that is the practice of biophilic design in the interior, and the psychophysical reactions of workers who work and act in such an environment. The results showed that there is indeed a link between the use of wood and overall employee satisfaction at work, lower absenteeism, higher levels of concentration and improved productivity. Workers who worked in an environment with less than 20 % wood surfaces were 30 % less satisfied with their jobs than workers who worked in an environment with a high proportion of natural wood surfaces.

A similar study was conducted in New Zealand (Ridoutt *et al*., 2002), where subjects were shown pictures of ten different office interiors that contained wood elements or no wood at all in the space. Respondents had to choose the interior that they can imagine most and least as their workspace and describe it with three different adjectives (out of a total of 24 offered). Offices with a wooden interior were characterized as places that create a sense of comfort and innovation, while offices without wood were described as places of discomfort and unimaginativeness.

Several studies have been conducted in Japan on the impact of wood on quality of life. One study (Anme *et al*., 2012) examined the health and behavior of elderly Japanese residents of a nursing home. Part of the respondents were in daily contact with wooden elements, while the other part used plastic products. The final results showed that those who used wooden products were much more talkative and sociable, and that there was a greater number of interactions that improved their emotional state.

There is a strong argument for the use of wood in the construction of schools and school interiors (Think Wood, 2021). Due to the properties of wood, cost-effective constructions and high-performance buildings are made that are safe, resistant, attractive and enable a healthy environment and the wellbeing of students. Thus, in Japan, a reduced incidence of influenza outbreaks among students in schools with wooden interiors has been reported.

Wood interior design is associated with higher occupant satisfaction. To illustrate, Watchman and colleagues (2017) conducted a post-occupancy survey of occupants in two multifunction rooms. One room had extensive wood finishing, while the other was devoid of wood. The rooms were otherwise similar. Occupants in the room with wood finishing were more satisfied with lighting, noise and temperature. The occupants described the wood room as bright, pleasant, modern and warm. These results obtained by studying the reactions of respondents in an environment where wood is present show that the human physical condition measured by criteria such as blood pressure and human mental condition measured by stress levels are greatly improved. Psychophysiological results on wood in the interior show that the response of the human body to stress is lower and productivity is higher than in the interior where wood is not present.

3.3.2 Stress relief
3.3.2. Ublažavanje stresa

Stress is one of the greatest causes of health problems in humans. It can manifest in many different ways and can also affect the way people function. When people are under stress, they may have difficulty focusing or socializing because they feel more anxious (Kemeny, 2003**)**. Research on the physiological effects of wood is relatively new, but there is now a growing number of studies on this topic.

In a Japan study (Ohta *et al*., 2005**),** the focus was to investigate the impact of wood on physiological and psychological implications on humans. One of the experiments was a comparison in the reactions of the respondents when looking at a wooden or white steel wall. In people who prefer wood as a finishing material, blood pressure dropped significantly when looking at a wooden wall, while in people who are not prone to wood as a building material there were no significant changes in blood pressure. When the viewing of the steel wall was examined, the results were somewhat different. Blood pressure remained unchanged in subjects who liked steel, but in subjects who did not like it an increase in blood pressure was observed.

Tsunetsugu and co-authors (2002) investigated people's reactions to the use of wood in residential areas. Heart rate and blood pressure were measured on subjects who were in rooms with or without wooden surfaces. The blood pressure and heart rate of the participants in the rooms with wood were lower than the values measured before entering the room, while the blood pressure and heart rate of those in the room without wood increased compared to levels measured before entering the room.

A few years later, the same group of researchers (Tsunetsugu *et al*., 2007) investigated changes in respondents who stayed in different rooms. The rooms were specific in that their surface was covered with a different percentage of wood (0 %, 45 % or 90 %). Heart rate and blood pressure were lower in subjects who stayed in a room with 90 % wood than in a room with 0 % wood. The survey found that a room with 45 % coverage was the most optimal because respondents said they felt most comfortable there.

One example is the addition of wood cedar boards and rice straw paper to the walls in hospital rooms (Ohta *et al*., 2008). It was measured that the level of stress (the level of cortisol was measured) was reduced in patients who stayed in these rooms, in contrast to patients who stayed in rooms with concrete walls.

Vast research was conducted in places such as hospitals. One study was conducted in a newly renovated waiting room in Bratislava hospital (Kotradyova *et al*., 2019**),** where respondents' heart rate, cortisol level and blood pressure were measured before, during and after their stay in the wooden room. Respondents described their emotions as predominantly satisfied or very satisfied, and their cortisol levels decreased by 7.5 %, which is evidence of reduced stress due to staying in rooms containing wood elements.

Several studies have also been conducted in schools where the level of stress in students has been examined. One such study took place in Austria, where Kelz and colleagues (2011) studied stress levels in students who attended wood-dominated classrooms and wood-free classrooms. Research has shown that heart rate variability increased during the school year in students who stayed in classrooms where there was no wood. It is an indicator of the activation of the parasympathetic nervous system, which acts in a way that reduces stress levels and promotes the body's healing and recovery functions.

Another one-year Austrian study (Grote *et al*., 2010) also examined stress levels in classrooms with linoleum floors and plasterboard walls and in classrooms with wooden interior on a sample of 52 high school students in a school equipped with two types of classrooms. Students in wooden classrooms had significantly lower heart rates and lower perceptions of stress.

Fell (2010) based his study on the role of wood and plants in reducing stress in the context of an office environment by measuring the two branches of the autonomic nervous system responsible for physiological responses to stress in humans. The respondents were assigned to one of four rooms: a room with wood and plants, a room with only wood but no plants, a room without wood but with plants, and a room without any wood or plants. The results of this study are similar to those conducted by Kelz *et al.* (2011) as it was found that the activation of the sympathetic nervous system was lower in the room where there was wood. The rate of measurable divergent stress thoughts in a wood-based office was half that of a wood-free office (Fell, 2010). Another study carried out in Slovakia (Vavrinsky *et al*., 2019**)** has shown how different colors and textures affect creativity in people by simulating different environments in virtual reality. The study was conducted using BCD applications, and measurements were performed using an EEG helmet and a monitor that measured heart rate and respiratory rate. The results showed that the environment in which both warm and cool colors were present and in which some of the natural materials such as wood and textiles were present positively affected the participants. Apart from the fact that such materials affect relaxation, they also have a great impact on successful problem solving and clarity of thinking. On the other hand, environments in which very bright colors and artificial materials dominated have led to creating stress in participants. People were tested by looking at and touching three walls of different textures. The wooden wall had the most positive effect because it was proven that looking at and touching that wall increased the brain activity of the subjects. Particleboard and white laminate walls did not have such a positive effect. The brownish wooden materials implemented in the room proved to be an ideal choice for a relaxing environment.

Furthermore, the implementation of wood in the interior for wall coverings has a positive effect on users, and especially on the reduction of stress levels as shown by measurable parameters (Rice *et al*., 2006).

3 DISCUSSION AND CONCLUSIONS
3. RASPRAVA I ZAKLJUČCI

The purpose of this paper was to review the results of previous research on the use of solid wood in the interior environment and its effects on the health of humans, as well as to define the main similar parameters by which wood in the interior affects people's behavior and the feeling of comfort and wellbeing.

A systematic review of knowledge about wood used indoors and its impact on health, and thus on the feeling of comfort, is given in Table 1.

Based on the studied literature, solid wood has a positive effect on the cognitive abilities and psychophysical state of humans, and thus on the feeling of comfort and wellbeing in the indoor environment. When there is wood in the environment, people are less exposed to stress and more productive. The balance of moisture in the air created by wood in interiors results in a sense of comfort and air quality. The surface of the wood has much better antibacterial properties than other materials, which is equally important to note considering the current situation in the world and the time we live in. All these qualities are generated through tactile stimulation and visual perception of solid wood. Considering all the above, solid wood in the interior is a desirable material for various wood products.

However, although it is a well-known fact that wood is a natural material that has a positive effect on humans, this review suggests that thirty-one separate studies might not be enough for a general conclusion about the positive aspects of a certain type of wood, i.e. for understanding which aspects of a particular type of solid wood have a stronger or weaker effect on human perception and wellbeing.

By applying the selected keywords, a greater number of papers investigating the subjective aspects of the use of wood in the interior than the objective ones can be seen. This result indicates that the subjective experience of the space and the feeling of comfort in the space ("I feel good") is more related to the psychological subjective perception than to the objective perception of the physical state of the user's body. It can therefore be concluded that it is necessary to combine subjective and objective methods for assessing the feeling of comfort in the environment. Further research should go in the direction of developing subjective questionnaires, models and methodologies that would give more precise results in unique measurements of the feeling of comfort in wooden buildings and interiors. This would provide more unambiguous instructions to designers, architects and manufacturers in the construction of healthy sustainable buildings and interior design.

Further in-depth research on this topic should go in the direction of deepening the understanding of whether solid wood and solid wood products (veneers, plywood, solid boards) increase the user's sense of comfort when installing wooden products made of certain types of wood in interiors of wooden sustainable buildings.

We hope that this work will encourage researchers to do further research on the visual and tactile perception of wood through various wood products in the

Table 1 Findings on wood used in indoor environment and its impact on wellbeing
Tablica 1. Zaključci o drvu koje se upotrebljava u interijeru i njegov utjecaj na dobrobit korisnika

Objective Results *Objektivni rezultati*	**Findings** / *Zaključci*	**Authors** / *Autori*
Air Quality – Humidity *kvaliteta zraka – vlažnost*	wood improves indoor air quality *drvo poboljšava kvalitetu zraka u zatvorenom prostoru*	Hameury and Lundström, 2004; Simonson *et al.,* 2002; Osanyintola and Simonson, 2006
	wood balances relative humidity *drvo uravnotežuje relativnu vlažnost*	Hameury and Lundström, 2004; Li *et al.*, 2012
	reduces heating and cooling, energy consumption *drvo smanjuje potrošnju energije za grijanje i hlađenje*	Osanyintola and Simonson, 2006
Antibacterial effects *antibakterijski učinci*	wood shows antibacterial properties *drvo ima antibakterijska svojstva*	Vainio-Kaila *et al.*, 2017; Laireiter *et al.,* 2013
	wood shows higher antibacterial properties than plastic *drvo ima bolja antibakterijska svojstva od plastike*	Schönwälder *et al.*, 2002; Milling *et al.*, 2005
	untreated wood shows higher antimicrobial activity *netretirano drvo pokazalo je veću antimikrobnu aktivnost*	Kotradyova, *et al.,* 2019; Hedge, 2015
Subjective results *subjektivni rezultati*	**Findings** / *Zaključci*	**Authors** / *Autori*
Visual perception *vizualna percepcija*	medium wood use in space *umjerena upotreba drva u prostoru*	Nyrud *et al.*, 2014; Tsunetsugu *et al.*, 2007
	knot free wood preferred *poželjno drvo bez kvrga*	Nakamura and Kondo, 2008
	vertically arranged wooden grain preferred *poželjniji vertikalni postav smjera teksture drva*	Nakamura *et al.,* 2019
	the color of wood creates warmth *boja drva stvara toplinu*	Masuda, 2004
Tactile stimulation *taktilna stimulacija*	causes less stress than other materials on the living body *uzrokuje manje stresa od drugih materijala na ljudski organizam*	Wang *et al.*, 2000; Morikawa *et al.*, 1998
	uncoated wood shows most positive relaxing effect *nepremazano drvo pokazalo je najpozitivniji opuštajući učinak*	Bhatta *et al.*, 2017; Sakuragawa *et al.*, 2008; Ikei *et al.,* 2017a; Berger *et al.*, 2006
Overall wellbeing results *ukupni rezultati dobrobiti*	**Findings** / *Zaključci*	**Authors** / *Autori*
Productivity *produktivnost*	better working conditions in view of lighting, noise and temperature *bolji radni uvjeti s obzirom na osvjetljenje, buku i temperaturu*	Watchman *et al., 2017*
	improves satisfaction in workplace *pospješuje zadovoljstvo u radnom prostoru*	Bergs, 2002; Knox and Parry-Husbands, 2018; Ridoutt *et al.*, 2002; Watchman *et al., 2017*
	improves emotional state of elderly *poboljšava emocionalno stanje starijih osoba*	Anme *et al.*, 2012
Stress relief *oslobađanje od stresa*	visual and tactile stimulation of wooden surfaces increases brain activity and promotes relaxation *vizualna i taktilna stimulacija drvenim površinama povećava aktivnost mozga i potiče opuštanje*	Vavrinsky *et al.*, 2019
	visual stimulation of wooden surfaces reduces blood pressure and stress *vizualna stimulacija drvenim površinama smanjuje krvni tlak i stres*	Ohta *et al.*, 2005; Ohta *et al.*, 2008; Kelz *et al.*, 2011; Grote *et al.*, 2010

interiors of sustainable buildings. All these findings can be a potential guide for greater use of wood in the interior design of sustainable timber buildings by wood processors, manufacturers, architects, and interior designers as well as for more vital branding of wood products in the market with the aim of increasing wellbeing in the indoor environments with an emphasis on furnishing sustainable public facilities.

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Corresponding address:

Associate Professor DANIJELA DOMLJAN, PhD
University of Zagreb,
Faculty of Forestry and Wood Technology, Svetošimunska 23, 10000 Zagreb, CROATIA,
e-mail: ddomljan@sumfak.unizg.hr