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EXPLORING REACTIONS TO WOOD DEFECTS: AN INITIAL STUDY INVESTIGATING PSYCHOLOGICAL/ PHYSIOLOGICAL RESPONSES AND CULTURAL DIFFERENCES TO KNOTS IN WOOD

Aayusha Chapagain[1], Paul Crovella[2]

ABSTRACT: Biophilia represents the inherent human affinity for nature, with wood serving as a biophilic material that positively affects well-being. While numerous studies have investigated the psychological and physiological effects of exposure to wood environments, the specific influence of wood defects remains largely overlooked. Integrating wood with defects into design is vital for maximizing wood utilization, especially given wood's role in reducing building-related carbon emissions and the fact that 30–40% of harvested wood is discarded due to wood defects. Although mass timber construction relies on stiffness and is generally unaffected by knots, such wood is often excluded from exposed areas. Therefore, it is crucial to include wood with defects for increased wood utilization. This study explores individuals' physiological responses (heart rate, blood oxygen, and stress levels), creativity, concentration, and psychological reactions to wood with and without defects. The results indicate that both the cubicle with defects and the cubicle without defects elicited favorable physiological responses. When creativity and concentration were assessed within each cultural group as well as the total participants, there were no significant differences between the two conditions. Additionally, participants from the Western culture group consistently demonstrated higher creativity and concentration scores across both conditions, although this difference may not be entirely attributed to the wood itself. Psychological responses varied between the two environments and two cultures, the results suggest that wood defects may not always lead to negative psychological impacts, in some cases, they may even reduce emotional tension. Cultural differences also appeared to influence how environments with wood defects are perceived and internalized.

KEYWORDS: Timber, Physiology, Psychology, Defects, Knots

1 – INTRODUCTION

According to the biophilic hypothesis, humans have an inherent desire to connect with nature, which fosters a positive perception of wood as a natural, warm, and health-promoting material [1];[2]. Numerous studies conducted over the years have focused on exploring the physiological and psychological responses of individuals when exposed to the biophilic element of wood and its environments. Covering interiors, including walls, ceilings, and floors, with wooden surfaces can influence both psychological and physiological responses [3]. These responses encompass visual, auditory, olfactory, and tactile stimulation from interior wooden surfaces [3].

Research has identified a correlation between the presence of wood and improvements in both physiological and psychological states [4]. Some studies have even found associations between the presence of wood and lower blood pressure, reduced stress levels, more positive emotions, and decreased depressive thoughts, with participants reporting sensations of warmth and induced calmness [4]; [5];[6];[7].

In a study [8], it was revealed that wood induces more positive emotions than plaster. The research [8] highlights the positive influence of wood on human psychological well-being and emphasizes the importance of considering multiple sensory modalities when investigating wood-human interaction.

[1] Author 1 Aayusha Chapagain, Department of Sustainable Resources Management, SUNY ESF, Syracuse, USA, achapaga@syr.edu

[2] Author 2 Paul Crovella, Associate Professor, Department of Sustainable Resources Management, SUNY ESF, Syracuse, USA, plcrovella@esf.edu

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However, existing research is often limited to specific geographical areas and lacks a broader exploration of people's psychological and physiological responses to certain wood characteristics like wood defects.

Most of the research on this topic has been carried out in Japan, potentially leading to findings that differ from those in Western countries. To mitigate this potential bias, this study categorizes cultural backgrounds into two broad groups: Eastern and Western cultures. The classification of cultures into Eastern and Western may be considered a colonial perspective and an oversimplification of the vast cultural diversity worldwide. However, this broad categorization is used here to provide a general perspective on whether culture affects how people respond to different characteristics of wood, and the study acknowledges the wide diversity of values, experiences, and perspectives within each group. The use of these terms is not intended to reinforce cultural stereotypes but to provide a comparative framework for understanding potential cultural influences.

Aim of Research

The primary objective of this research is to explore differences in responses to wood defects (knots), examining whether psychological and physiological reactions differ between two broadly generalized cultural backgrounds-Eastern and Western.

1.1. Significance of Research

When exploring ways to expand wood utilization, it is vital to consider the potential for increased use, including that with defects. Since the ratification of The Paris Agreement at the United Nations in New York in 2016, nations globally have actively engaged in initiatives focused on resource conservation, enhanced energy efficiency, and diminished carbon emissions [9].

In the practical realm of wood production, safeguarding forest resources and optimizing wood utilization have gained increased significance [10]. Wood processing industries have consistently aimed to maximize yields in their operations, thereby minimizing volume loss of wood [10]. Notably, within wood processing, only 50 to 70% of logs are utilized after the removal of defects, bark, and branches [11].

Additionally, the use of wood in construction helps in reducing the carbon emissions in building sector. The building sector plays a crucial role in tackling climate crisis, responsible for 36% of global energy use and 39% of energy-related carbon emissions[12]. This is partly driven by the extensive reliance on fossil fuel-based, carbon-intensive materials like concrete and steel [12]. Bulk material production, particularly iron, steel, cement, lime, and plaster, are the largest contributors to these embodied carbon emissions [13]. Manufacture of glass, cement, and steel alone accounts for 11% of energy and process-related emissions[14].

Mass timber construction, driven by innovative engineered wood products like Cross-Laminated Timber (CLT), offers significant potential for reducing embodied carbon emissions in the building sector [12]; [15]. Mass timber construction presents a sustainable alternative, potentially achieving a significantly lower embodied carbon footprint compared to traditional building methods such as concrete and steel structures [16]; [17]. The use of mass timber primarily depends on its stiffness, which is minimally influenced by the presence of knots [18]. However, wood containing knots is typically avoided on exposed surfaces due to aesthetic considerations.

For these reasons, it is crucial to consider the inclusion of wood with knots for increased wood utilization.

2 – BACKGROUND

2.1 WOOD DEFECTS AND THE PSYCHOLOGICAL AND PHYSIOLOGICAL RESPONSES

Wood defects primarily fall into three categories: growth defects resulting from physiological factors, damage induced by pests due to pathological reasons, and defects arising from processing influenced by human factors [19]. Among the growth defects in timber, knots, cracks, slashes, burrs, and resin capsules are noteworthy, with most of these defects arising from the natural growth of trees [19]. However, in the context of wood panel utilization, these are considered as wood defects. **For this study, we will specifically focus on knots.**

Knots emerge as a distinctive surface feature in wood, originating from the remnants of branches within the tree trunk [20]. The growth of new wood layers over the existing ones during seasonal growth embeds branch bases more deeply in the trunk as the main stem diameter expands [21]. Numerous studies on wood defects are carried out in Eastern countries, particularly in Japan. A study conducted in Japan [20] highlights that while knots indicate the wood's origin from a living tree, they are considered undesirable surface attributes that substantially diminish both the mechanical properties and aesthetic appeal of lumber.

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Another study in Japan found that the knotty wall panels evoke natural impressions [22], but the agreeable impressions diminish as the number of knots increases [22]; [23].

Research has also been conducted in Western countries, including Sweden, Norway, and the United States. A study in the U.S. [24] suggests that wood with a limited number of surface knots is generally preferred, as indicated by several research studies focusing on this pattern. Survey findings suggest that a few knots are intriguing, while an abundance of knots is generally disliked [24]. Eye-tracking systems, which monitor the movement of the eyes across an image and record pauses at specific points, reveal that wood with numerous knots tends to elicit more frequent pauses [24]. This observation suggests that more cognitive effort may be required to process what is being viewed.

Some studies found a preference among consumers in Northern Europe for clear surfaces over knotty ones [25]. The selection of knotty surfaces hinges on achieving a delicate balance between visual harmony and activity [26]. A study in Norway suggested that there is a significance of a homogeneous appearance and medium color strength in consumer preferences for knotty wood deck products [27]. Similarly, another study in Norway underscored the experimental link between surface homogeneity and preferred wood products, an association significantly influenced by the presence of knots [29].

Some studies have experimentally delved into the physiological impact of knots on wood surfaces as visual stimuli for humans [28]. A study in Japan [7] employed two full-sized wall panels, a knotty hinoki (Japanese cypress) wall and a plain white steel wall, to compare the physiological and psychological responses evoked by visual stimulation. The results demonstrated that visual stimulation using the knotty hinoki wall panel significantly reduced blood pressure among participants who favored the knotty wall panel, with no significant increase in blood pressure among those who did not favor it. Other studies conducted in Japan employed eye-tracking techniques to explore the impact of knots, revealing a robust linear correlation between the probability of fixations on knots and their subjective noticeability[29].

Some specific studies seem to play a crucial role in establishing whether the dislike of knots is an inherent physiological reaction or a learned preference. A study [30] evaluated the physiological effect of knotty images as visual stimuli, employing well-prepared full-scale knotty and clear wooden wall images. Oxyhemoglobin concentration (oxy-Hb) in the left and right prefrontal cortex, an indicator of brain activity, and heart rate variability (HRV), an indicator of autonomic nervous activity, were assessed. The left prefrontal cortex is generally associated with positive emotions and approach motivation, verbal processing, working memory and semantic processing whereas the right prefrontal cortex is associated with negative emotions and withdrawal motivation, spatial processing, impulse control, emotional regulation and contextual monitoring. Results indicated that the knotty wooden-wall image sedated right prefrontal cortex activity and enhanced parasympathetic nerve activity compared with before stimulation. Clear wooden wall images sedated the left prefrontal cortex activity compared with the control and suppressed sympathetic nerve activity compared with before stimulation. Wall images comprising knotty or clear wood, when used as a visual stimulus, had a physiological relaxation effect among adult women in their 20s [30] .

Despite negative psychological effects associated with knots, confirmation of similar negative physiological effects is yet to be established.

2.2. CULTURE

Culture is a system of shared beliefs, values, customs, behaviors, and artifacts that the members of a society use to cope with their world and with one another, and that are transmitted from generation to generation through learning [31].

Eastern culture and Western culture are two diverse ways of life [32]. Eastern culture, predominantly found in countries like China, Japan, and India, emphasizes collectivism[33], harmony[34], and respect for authority[32]. It places great importance on traditions, spirituality[35];[36], and family values. On the other hand, Western culture, prevalent in countries like the United States, Canada, and most of Europe, values individualism[32], personal freedom, and innovation. It emphasizes the pursuit of personal goals, equality[32], and democratic principles. While Eastern culture tends to be more conservative and rooted in ancient customs, Western culture is often more progressive and open to change. Despite their differences, both cultures have contributed immensely to the global society and have their own unique strengths and weaknesses.

3 – PROJECT DESCRIPTION

The main objective of the research is to find the variances in psychological and physiological responses towards wood defects and its association with the people's cultural background. Cultural variances in psychological responses toward wood defects were studied with the help of survey, psychological forms and (creativity and concentration) tests in the experiment. In contrast, the physiological measurements were carried out with the help of an Amazfit Band 7® device. In short, to achieve the major objective, qualitative and quantitative methods (*Figure 1*), specifically survey, psychological forms, creativity and concentration tests and physiological measurements, were chosen to delve into the cultural nuances surrounding wood defect responses.

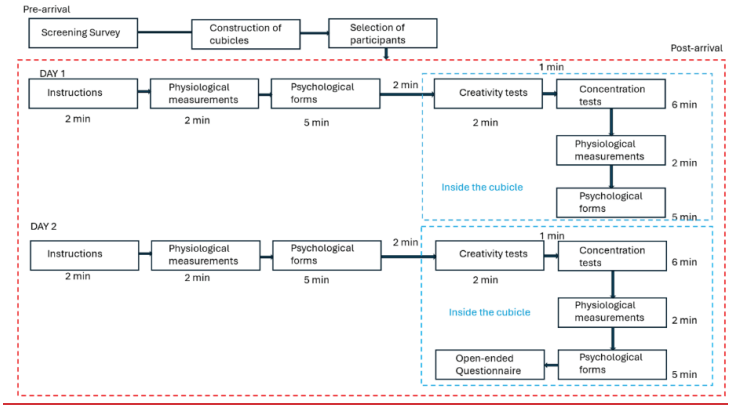

Figure 1. Diagram showing the different stages of research study

4 – EXPERIMENTAL SETUP

4.1. Participants Pre-Arrival

This stage took place before the day of the actual experimental design. It included all the preparation stages like participation selection, construction of cubicles and availability survey.

1) **Sample Size calculation:** The sample size of N=59 was chosen from another relevant paper [37], where the sample size and power calculations were conducted to ensure sufficient statistical power for the study. Later, the sample size was adjusted to N = 60, ensuring equal representation with 30 participants from Eastern culture and 30 from Western culture. It is important to note that participants self-identified with their respective cultural backgrounds.

2) **Participant Selection:** A total of 60 student participants were selected. Students from different universities in Syracuse were invited to participate. However, students from outside of Syracuse were not eligible. Recruitment was done with the help of a screening survey consisting of two parts: qualifying questions (the students should be above 18, they should be students studying in Syracuse, and they should consent to participate) and the main questionnaire related to participant's cultural background. Based on the information provided, qualified participants were categorized into two groups-Eastern culture and Western Culture.

3) **Construction of Cubicles:** Two cubicles were erected, one constructed with 'wood without defects' and the other utilizing 'wood with defects'. The chosen wood specimen was White Pine. Given the objective to gauge psychological and physiological responses toward wood defects, it was crucial to have distinct defects visible to observers. White Pine's white color aids in making defects clear. Furthermore, the grades of wood selected were "S4S D Select Grade" in 1 x 6 -12' and "Tongue and Grove Standard" in 1 x 6 - 14', enhancing its suitability for the study. The wood in the form of Tongue and Groove was easier to assemble, whereas S4S needed to be converted into Tongue and Groove using router bits. The wood in the cubicles were applied with Olympic Water Guard Clear Exterior Waterproofing Wood Sealer) ™ which is a water-based penetrating finish typically used in the industry.

4) Availability and Invitation: After determining the study dates, participants received a Calendly® Invitation prompting them to choose their preferred day and time from a list of available options between the months of

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February and March, 2025. Once participants made their selections, they were invited to visit the research site on their chosen date.

4.2. **Participants Arrival and Experimental Design**

This stage took place on the day of the experimental design, following the completion of preparatory stages and ensuring all arrangements were in place. It involved administering pre- and post-psychological forms, conducting physiological measurements, and performing concentration and creativity tests. The experiment was repeated twice on separate days. All tests and procedures remained consistent throughout both days.

5) **Physiological measurements:** After the arrival of the participants, they received an Amazfit Band 7 ® to monitor their physiological responses. The wristband, worn on the left wrist, measured parameters such as heart rate variability, blood oxygen level, and stress level. The Band 7® offers a feature that allows users to simultaneously measure three health metrics—heart rate, blood-oxygen saturation (SpO_2), and stress level—with a single tap, providing results in as fast as 45 seconds.

6) **Pre-Psychological forms + post-psychological forms:** After the physiological measurements, participants were handed three psychological forms, specifically the Perceived Stress Scale-4 (PSS-4), PANAS and Restoration Outcome Scale (ROS).

7) **Creativity and Concentration test:** Upon entering the cubicle, participants completed the creativity and concentration tests. For the creativity Tests or Wallach and Kogan's creativity assessment, participants were tasked with generating as many items as possible that fit within a broad category within two minutes. For example: Name things with wheels. The scoring of this test involves four components: fluency, flexibility, originality, and elaboration. Wallach-Kogan tests are highly reliable tests for determining creativity level of the people [38].

For the concentration tests (word test), the participants identified 28 words within a rectangular grid consisting of 11 x 19 letters. These words could be read in multiple directions: right to left, left to right, top to bottom, bottom to top, and diagonally. The students were given six minutes to complete the task. [38]

9) **Data Analysis:**

a. The physiological data, including heart rate, blood oxygen level, and stress level, were analyzed using a paired t-test in Minitab®, assuming a 95% confidence interval. The test was conducted with a hypothesized difference of zero and an alternative hypothesis stating that the difference is not equal to the hypothesized value.

b. The creativity test was initially evaluated manually, assigning scores based on fluency, flexibility, elaboration, and originality. Following this, the results were analyzed using a paired t-test in Minitab®, assuming a 95% confidence interval. The test was conducted with a hypothesized difference of zero and an alternative hypothesis that the difference is not equal to the hypothesized value.

The concentration test was scored by the number of words they could find from the puzzle out of 28 words. This was then converted into percentage and paired t-test was used to analyze this data.

c. The psychological responses were analyzed using the R programming language®, employing the Wilcoxon signed-rank test for statistical evaluation. This non- parametric test is used to compare two related (paired) samples, particularly when the data is ordinal or when the assumptions of a paired t-test are not met.

5 – RESULTS

The data analysis provided results for physiological and psychological responses, creativity and concentration level, first for the total number of participants, then separately within Eastern and Western cultural groups for 'with and without' conditions.

Physiological measurements

The results show no statistically significant change in heart rate before and after being in the cubicle with wood defects for the total participants. However, for the total participants, the heart rate was significantly lower while participants were in the cubicle without wood defects compared to before entering it. This trend is also observed within both Eastern and Western cultural groups, where a statistically significant reduction in heart rate (at the 10% level) occurred in the cubicle without defects. No such difference was found in the cubicle with defects.

The results indicate no statistically significant difference in blood oxygen levels within the Eastern and Western cultural groups individually, before and after being in either the cubicle with or without defects. However, for all participants combined, the difference in blood oxygen levels before and after being in the cubicle with defects is significant at the 10% level, with an observed increase in oxygen levels following exposure. There was no significant difference observed before and after entering the cubicle without defects for all 60 participants.

The results show no statistically significant change in stress levels among all 60 participants before and after being in either the cubicle with defects or the cubicle without defects. This pattern also holds true when analyzing the Eastern and Western cultural groups separately, no significant differences were found in stress levels before and after exposure to either cubicle type.

Creativity and Concentration tests

Creativity tests: The results revealed no statistically significant difference in creativity levels between cubicles **with** wood defects and those **without** defects among the total 60 participants. The same outcome was observed when the analysis was conducted separately within the Eastern culture group (30 participants) and the Western culture group (30 participants).

When the analysis was done between the Eastern and Western cultural groups, Western participants scored significantly higher than Eastern participants, averaging 11 points more when exposed to wood with defects, and 7.93 points more when exposed to wood without defects.

Concentration tests: Like the creativity tests, the results revealed no statistically significant difference in concentration levels between cubicles with wood defects and those without wood defects among the total 60 participants. The same outcome was observed when the analysis was conducted separately within the Eastern culture group (30 participants) and the Western culture group (30 participants).

When exposed to cubicles with wood defects, participants from the Western culture group exhibited significantly higher concentration levels, on average, 21.09 percentage points more than their Eastern culture counterparts. Similarly, in cubicles without wood defects, Western participants outperformed Eastern participants in concentration by an average of 22.84 percentage points.

Psychological responses

The psychological response results, obtained from PANAS, ROS, and PSS-4, revealed significant differences in certain variables among the 60 participants. When comparing their responses inside cubicles **with** wood defects versus outside the cubicle, four variables: upset(↓), guilty(↓), jittery(↓), and the feeling of difficulties piling up(↓), showed statistically significant differences. Similarly, when participants were inside the cubicle **without** wood defects, six variables: interested(↓), excited(↑), attentive(↓), jittery(↓), calm(↑), relaxed, and restored(↑), were found to be statistically different compared to when they were outside. This showed that more differences in psychological responses were observed when they were in cubicles without defects in comparison to the cubicles with defects.

In addition, the psychological response results, obtained from PANAS, ROS, and PSS-4, revealed significant differences in certain variables within the Eastern participants for 'with and without' conditions. When comparing their responses inside cubicles **with** wood defects versus outside the cubicle, four variables: interested (↓), upset (↓), determined (↑), difficulties piling up (↓) showed statistically significant differences. Similarly, when participants were inside the cubicle **without** wood defects, two variables: strong (↓) and attentive (↓) were found to be statistically different compared to when they were outside. This showed that more differences in psychological responses were observed when they were in cubicles **with** defects in comparison to the cubicles **without** defects for the Eastern participants.

For the Western participants, when comparing their responses inside the cubicles **with** wood defects versus outside the cubicle, five variables showed significant differences: Hostile (↑), Proud (↓), Alert (↓), difficulties piling up (↓) and restored and relaxed (↑). Similarly, when participants were inside the cubicle **without** wood defects, six variables: Interested (↓), Distressed (↓), Excited (↑), unable to control important things (↑), calm (↑) and restored and relaxed (↑) showed significant differences. This showed that more differences in psychological responses were observed when they were in cubicles without defects in comparison to the cubicles with defects.

Eastern VS Western

1. In Cubicles with Wood Defects:

The participants from Eastern Culture showed significant changes in 4 variables: (↓) Interested, (↓) Upset, (↑) Determined and (↓) Difficulties piling up. The participants from Western Culture showed significant changes in 5 variables: (↑) Hostile, (↓) Proud, (↓) Alert, (↓) Difficulties piling up and (↑) Restored and relaxed. Pattern observed was a mixed emotional response, some negative emotions like hostility increased, while stress-related indicators and restoration also improved.

2. In Cubicles without Wood Defects:

For the participants from Eastern Culture, only 2 variables showed significant changes: (↓) Strong and (↓) Attentive. For the participants from Western Culture, 6 variables showed significant changes: (↓) Interested, (↓)

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Distressed, (↑) Excited, (↑) Feeling unable to control important things, (↑) Calm and (↑) Restored and relaxed.

6- DISCUSSION

The physiological measurement results revealed a statistically significant reduction in heart rate when participants were in the cubicle without defects, both across all participants and within the Eastern and Western cultural groups individually. In contrast, no significant change in heart rate was observed in the cubicle with defects for any group. This suggests that participants may have felt calmer in the defect-free cubicle, though the absence of significant change in the other condition also implies they were not notably stressed in the cubicle with defects. Interestingly, blood oxygen levels increased significantly in the cubicle with defects at the 10% significance level for the full participant group, while no significant changes in oxygen levels were found in the cubicle without defects or within either cultural group for both conditions. Similarly, stress levels remained statistically unchanged across all participants and within cultural groups, regardless of the condition. Overall, the findings suggest that both cubicle types may have a positive physiological effect on participants.

The creativity and concentration test results from 60 participants revealed no statistically significant difference between cubicles with wood defects and those without. This finding held true within Eastern and Western cultural groups separately, indicating that the presence or absence of wood defects did not impact participants' creativity or concentration levels.

However, participants from the Western culture group demonstrated significantly higher concentration levels and higher creativity level than Eastern culture group in both cubicles 'with and without' wood defects. The fact that Western culture participants consistently scored higher on both concentration and creativity tests across both conditions (with and without defects) suggests that the difference may not be solely due to wood conditions. Instead, it could be influenced by pre-existing differences between the two cultural groups in terms of cognitive abilities, educational background, cultural attitudes toward creativity/concentration, or familiarity with such tasks.

Psychological responses, measured through PANAS, ROS, and PSS-4, revealed several significant changes depending on the presence or absence of wood defects in cubicle environments. Overall, more psychological differences emerged in cubicles without wood defects, particularly in the Western group, which reported increased feelings of excitement, calmness, and restoration, suggesting a more positive emotional state. Conversely, cubicles with wood defects were associated with reduced negative emotions (e.g., upset, guilty, jittery), indicating a subtle calming effect, though the number of significantly affected variables was fewer.

In cultural breakdowns, Eastern participants showed more psychological shifts in cubicles **with** defects, including increased determination and decreased stress indicators. Western participants, however, experienced greater emotional variation in cubicle **without** defects, including both reduced distress and enhanced calm. The findings suggest that wood defects may not always lead to negative psychological impacts, in some cases, they may even reduce emotional tension.

7 – CONCLUSION

The study examining physiological and psychological responses toward wood with and without defects, yielded several notable findings. Physiological data revealed benefits in each setting: the cubicle without defects lowered heart rate, whereas the cubicle with defects raised blood-oxygen levels. Similarly, the results suggest that wood defects may not always lead to negative psychological impacts, in some cases, they may even reduce emotional tension.

The main limitation of the study is the broad classification of cultures into Eastern and Western groups. The study acknowledges the wide diversity of values, experiences, and perspectives within each group. The use of these terms is not intended to reinforce cultural stereotypes but to provide a comparative framework for understanding potential cultural influences. Future research can explore how diverse cultural background encompassing individuals with diverse nationalities, ethnicities, associated cultures, and varying levels of connection to their ancestral culture influence physiological and psychological reactions towards wood defects along with consumer preferences and pricing. Additionally, studies can investigate the relationship between socio-demographic factors and individuals' reactions to wood defects. Another potential avenue for research is examining how people's perceptions and responses evolve over time. Future studies have the potential to provide deeper insights into wood defects and their impact on people, which could contribute to reducing wood volume loss caused by wood defects.

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