Sys Rev Pharm 2020;11(11):523-528
A multifaceted review journal in the field of pharmacy

The Selection of Environmentally Friendly Wood for Raw Materials in the Creative Industries

Sushardi[1], Adi Ruswanto[2], Sri Gunawan[2] Idum Satia Santi[2], Mohamed Nor Azhari Azman[2,3], Nuraeni Dwi Dharmawati[2] Bambang Heri Isnawan[4]

[1]Faculty of Forestry, Institut Pertanian STIPER Yogyakarta, Indonesia
[2]Faculty of Technical and Vocational, Universiti Pendidikan Sultan Idris, Malaysia
[3]Universitas PGRI Yogyakarta, Indonesia
[4]Faculty of Agricultural, Universitas Muhammadiyah Yogyakarta, Indonesia
Corresponding email: sushardi@instiperjogja.ac.id

ABSTRACT

The global economic crisis that hit the world turned out to cause a decline in exports. Therefore, in need of creative industries in raw materials production process and marketing. One of the creative efforts is the selection of wood raw materials for the industry is by using environmentally friendly wood species because it can reduce global warming. Still, the selling value of products in the export market is very high. The study design used a complete randomised design with an advanced Tukey test based on one factor, which is the types of wood that are Sengon, Waru Gunung, and Johar wood. The parameters observed are specific gravity, wood colour, adhesive strength, and formaldehyde emissions. The results showed that are Sengon, Waru Gunung, and Johar wood have different specific gravity, wood colour, and formaldehyde emissions. The average density of Sengon wood is 0.236, Waru Gunung wood is 0.570, and Johar wood is 0.654. The adhesive strength of Sengon wood 41.948 kg/cm^2, Waru Gunung wood is 45.555 kg/cm^2, and Johar wood 54.040 kg/cm^2. Besides, the formaldehyde emissions for Sengon wood is 0.575 ppm (0.575 x10-3 ug/ml), Waru Gunung wood 0.462 ppm, and Johar wood 0.473 ppm. The higher the wood specific gravity, it will result in the wood colour and lower formaldehyde emissions. Wood with medium to high density (Waru Gunung and Johar) acknowledged as the environmentally friendly woods, and it can be used as raw material for creative industries.

Keywords: Sengon, Waru Gunung, Johar, specific gravity, stickiness, wood damage, formaldehyde emissions

Correspondence:
Sushardi
Faculty of Forestry, Institut Pertanian STIPER Yogyakarta, Indonesia
Email: sushardi@instiperjogja.ac.id

INTRODUCTION

Sustainable and environmentally friendly use of materials is an important goal of many interior design and construction companies (Haavikko et al., 2019). It takes a creative industry to make innovative efforts in maintaining its industrial activities in the form of creativity in raw materials, production processes, and marketing (Kiroff, 2019). One of the creative endeavours in selecting wood raw materials for the industry is choosing wood species that are environmentally friendly to reduce global warming, and the selling value of products in the export market is very high (Islam & Bhat, 2019). Besides, the plant is also one initiative for environmentally friendly ecosystems that can reduce global warming (Khanali et al., 2020). It is because plants are the most effective carbon emissions absorbent (Jiang et al., 2020). Plants that contain wood have extractive components related to their ability to absorb carbon emissions.

The use of wood species as industrial raw materials must be adjusted to the wood's nature to produce good quality forest products. Each type of wood has a specific nature due to the growth patterns resulting from a combination of the influence factors of growth and the genetic characteristics of the wood species that produce the inherent properties of adhesive wood (Haavikko et al., 2019). One factor that has been known and clearly understood is the density of wood and its effect on quality. Wood density has a positive correlation with wood strength and formaldehyde emissions. Many efforts have been taken to improve product quality by using wood raw materials from environmentally friendly wood species to reduce global warming. The selling value of products in the export market is very high (Adhikari & Ozarska, 2018). As a result, currently, the industry needs raw materials that are sustainable and environmentally friendly (Teuber et al., 2016).

Wood is a versatile raw material and the only renewable construction material. The manufacture of wood products and structures consumes little energy compared to similar products and design made of other materials. Unlike other materials, most of the energy needed to manufacture wood products is derived from renewable energy sources (Glasenapp et al., 2019). The objective of this research paper is to determine specific gravity, stickiness, wood damage, and formaldehyde emissions of Sengon, Waru Gunung, and Johar wood. It is essential to know the types of environmentally friendly wood to be used as raw materials for creative industries (Dronyuk et al., 2019).

MATERIAL AND METHODS

The wood used in this research are Sengon wood (*Paraserianthes falcataria* (L.) *Nielsen*), Waru Gunung wood (*Hibiscus similis*), and Johar wood (*Cassia siamea* LAMK). A 10-years-old Sengon wood was obtained from Maguwoharjo village, Sleman district, and a 12-year-old Waru Gunung wood from Samigaluh village, Kulon Progo district. Then, a 27-year-old Johar wood was obtained from Ngawen village, Sleman regency. The adhesive used is urea-formaldehyde type UA-125, with powdered ammonium chloride hardener (HU-SPP). Adhesives and hardener are obtained from P.T. Palmolite Adhesive Industry on Jalan Brantas No. 1 Probolinggo. For this research, the material is tapioca flour, obtained from the shop "Mirota Kampus" Jl. Kaliurang Yogyakarta. The equipment used to determine specific gravity, including saws, drying ovens, measuring cups, and goblets. The tools used for the manufacture, testing of block boards, and formaldehyde emissions are circular saws, levellers, cold press, scroll saws, water batches, mechanical testing machines, scales, callipers, and spectrophotometers, and others.

The preparation for testing the specific gravity by using a sample with a dimension of 1.9cm x 2.5cm x 5cm, firmness, and formaldehyde emissions with a size of 17cm x 15cm x 1.9cm. Wood specific gravity test is carried out by utilising a sample measuring its dimensions in an air-dry state (Vku), then it is blended at a temperature of 103+2°C so that the kiln dry weight (Bkt) is obtained. The specific gravity is calculated by the formula (Adhikari & Ozarska, 2018).

$$\text{Bjku} = \frac{\text{Bkt/ Vku}}{\text{R Air}}$$

Information: Bjku = dry wood specific gravity
Bkt = kiln dry weight (g)
Vku = volume of air dried (cm^3)
R Water = water density at 4 °C ($1g/cm^3$)

The wood colour test was carried out using the four-place colourimeter tool in a sample measuring 17 cm^3 x 15 cm^3 x 1.9 cm^3. Colour values are presented in per cent Y or L, colour parameters X, Y, and A, and B cannot be used because they are parallel with the values Y and L (Petchpoung et al., 2020). Testing of stickiness and wood damage is done by; 1) Placing wood in the block shear press test equipment to find the amount of pressure load (kg), 2) Calculating the adhesive strength in the form of maximum compressive strength (kg/cm^2). The amount of stickiness calculated by the following formula (Sushardi & Azman, 2020):

$$KR = \frac{P}{A} \text{ kg/cm}^2$$

Note: A = The area of the sliding plane (cm^2)
P = Maximum load (kg)
KR = Stickiness (kg/cm^2)

The method of testing and evaluating formaldehyde emissions is carried out according to the American or IHPA standards (Nguyen, 2018).

The study used factorial experiments with ten replications arranged in a Completely Randomised Design (CRD), which consists of Sengon wood (*Paraserianthes falcataria* (L.) Nielsen), Waru Gunung wood (*Hibiscus similis*), and Johar wood (*Cassia siamea* LAMK). Based on these factors, a combination treatment can be made with 3x10 =30 samples. In speeding up the process of analysis, the research data were analysed using the SPSS program.

RESULTS

Specific Gravity

The average density of Sengon wood is 0.236, Waru Gunung wood is 0.570, and Johar wood with 0.654, which defines that all these woods have different specific gravity as presented in Table 1. The average density value of Sengon wood is between 0.22 to 0.25 (Dupleix et al., 2013). Sengon wood includes light wood with an average specific gravity of 0.33 and a strong class IV to V, and a durable class IV to V (Sushardi & Azman, 2020). Sengon wood can be used as a building material, especially in rural areas, crates, particleboard, fibreboard, cement wool board, pulp and paper, and handicraft items (Sushardi & Azman, 2020). The average density value of Waru Gunung wood ranges from 0.55 to 0.58 (Werdin et al., 2020). Waru Gunung wood is categorised in the durability class III, strength class II to III with a specific gravity of 0.63 (0.52 to 0.73). Sungkai wood is used as a material for household furniture, beautiful veneers, decorative walls and cabinets, door, and window frames (Saini & Singh, 2020). The average value of Johar wood specific gravity ranges from 0.68 to 0.69. The colour of Johar wood is dark brown, and the sapwood is light brown with relatively coarse wood texture; thus, the direction of the fibre is straight and combined (Nguyen, 2018). Younger wood is white with black lines, while older wood is beautifully dark (Bernabei et al., 2018). Johar wood is included in the durability class III, strength class II to III, with a specific gravity of 0.63 (0.52 to 0.73) (Sushardi & Azman, 2020). Johar wood is used as materials for household furniture, and other building materials (Kumar et al., 2020). The relationship between Sengon, Waru Gunung, and Johar wood based on the wood specific gravity can be seen in Figure 1.

Table 1. Value of Specific Gravity, Bonding Strength and Formaldehyde Emissions Sengon, Waru Gunung and Johar wood

No	Parameter	Wood Type		
		Sengon	Waru Gunung	Johar
1.	Specific gravity	0.236 a	0.570 b	0.654 c
2.	Wood colour	61.92 p	49.31 q	17.68 r
3.	Adhesive strength (kg/cm^2)	41.948 p	45.555 q	54.040 r
4.	Formaldehyde Emissions (ppm)	0.575 x	0.462 y	0.473 z

Note: Numbers followed by the same letter in each factor and parameter indicates no real difference

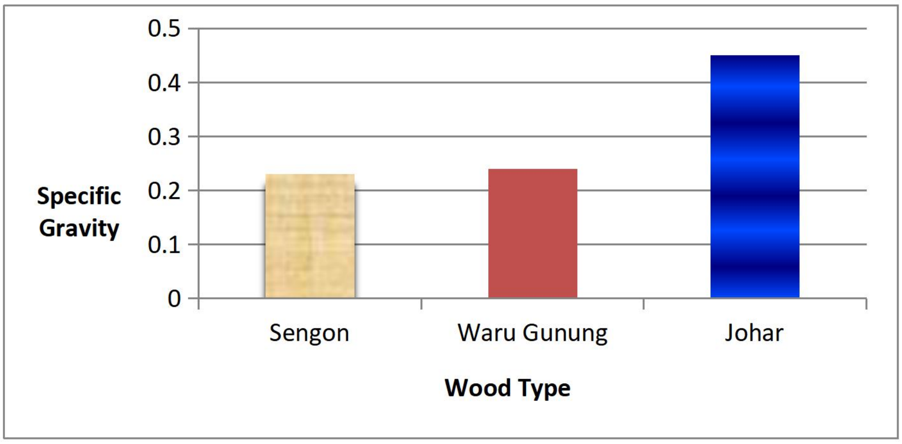

Figure 1. Relationship between Sengon, Waru Gunung and Johar Wood Species on Specific Gravity

Wood Color

The average value of the colour of Sengon wood is 61.92, Waru Gunung wood is 49.31, and Johar is 17.68, which indicates that it is different from each other (Table 1 and Fig 2). The colour of the wood that can be detected is a macroscopic appearance on the wood surface that can be seen directly with the naked eye or a colourimeter tool. The colours shown by wood are essentially the result of a lot of the least extractive wood. Light wood colour means the wood contains extractive low wood dyes; otherwise dark wood colour due to high extractive content. Sengon wood has a lower extractive rate compared to Waru Gunung and Johar wood. The colour of light wood is suspected to be associated with a type of material or extractive that supports high emissions (Solt et al., 2019).

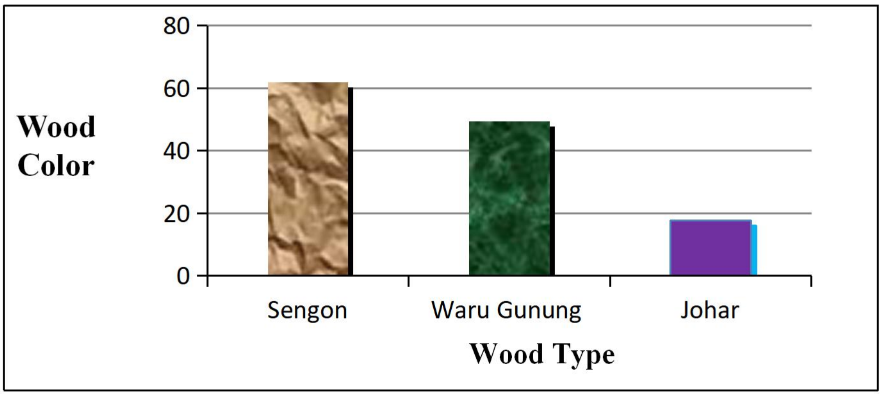

Figure 2. Type of Sengon, Waru Gunung and Johar wood with the wood colour

Adhesive Strength (kg/cm^2)

The average value of adhesive strength was 41.948 kg /cm^2, 45.455 kg/cm^2, and 54.040 kg/cm^2 (Table 1). Sengon, Waru Gunung, and Johar have the adhesive strength, but it is significantly different. From these results, it can be seen that the lower the specific gravity of the wood, the lower stickiness produced. The relationship between the wood species and stickiness of air-dry conditions can be seen in Figure 3.

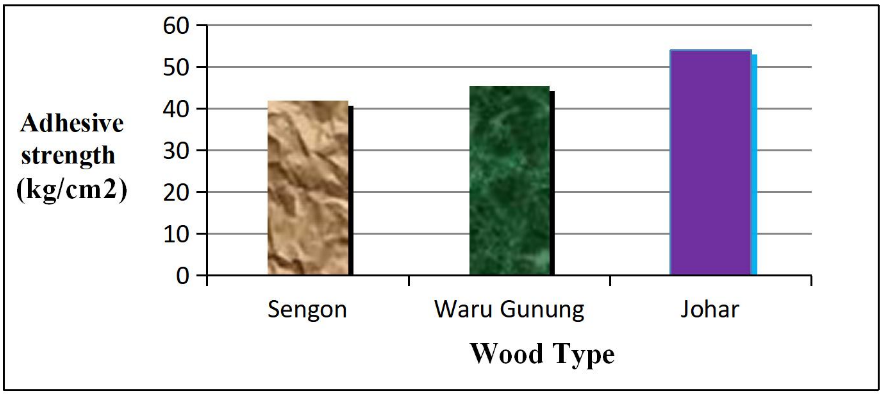

Figure 3. The relationship of wood species to the stickiness of air-dry conditions

Formaldehyde Emissions (ppm)

The average formaldehyde emission value of Sengon wood is 0.575 ppm (0.575 x10-3 ug/ml), Waru Gunung 0.462 ppm, and Johar 0.473 ppm (Table 1). The average value of formaldehyde emissions produced by Sengon wood is higher than Waru Gunung and Johar. As known, Sengon wood has a lower specific gravity (Bj=0.236), compared to Waru Gunung wood (Bj=0.570) and Johar wood (Bj=0.654), so the proportion of gravity volume is higher. The lower the density of wood, the higher the ratio of vessels (pores) (23.10%), so that formaldehyde emissions occur quickly. One of the causes of formaldehyde emission is wood porosity (Zhang et al., 2019).

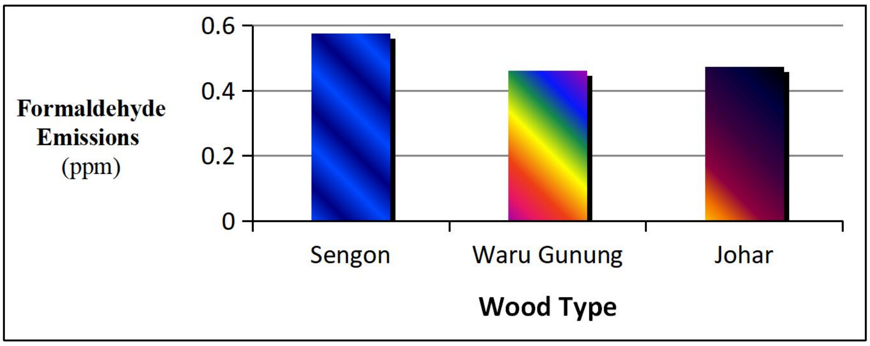

Figure 4. Relationship between wood species and formaldehyde emissions

DISCUSSION

The woods specific gravity can be divided into three, that is wood with lightweight if the specific gravity is less than 0.36, medium density wood has a specific gravity of 0.36 to 0.56, wood with a high specific gravity that is more than 0.56. Hence, the specific gravity can indicate the strength of wood. Based on the specific gravity, Sengon wood resulted in the light specific gravity. Meanwhile, Waru Gunung wood is categorised with medium-specific gravity, and Johar wood has a high specific gravity. Specific gravity is an essential factor in determining wood quality. In general, wood with high specific gravity will have better strength and vice versa (Gillerot et al., 2018).

Wood, with high specific gravity, has a higher strength when compared to the wood that has a lower specific gravity (Basin et al., 2017). The higher the density of wood, the thicker the cell wall, so it requires relatively more pressure to break it (Sushardi & Azman, 2020). The specific gravity is closely related to the strength of the adhesive or stickiness of wood. Specific gravity is closely related to the power of adhesive or sticky wood. It means that with the increment in wood density that is glued together, the adhesive strength of the wood is expected to be higher too (Oh et al., 2019).

The extractive content of Sengon wood soluble in cold water is between 3.37% to 4.40%, in hot water between 3.96% to 7.49%, soluble Bensen alcohol between 3.33% to 5.86%, soluble in NaOH 1% between 14.85% to 20.83%, and ether between 3.53 to 5.50%. The range of extractive levels of soluble alcohol Bensen 3.93 to 5.83%, cold-water-soluble 2.07 to 3.23%, and hot water soluble 4.12 to 5.13% (Bockel et al., 2019). Bright wood colour, when used for the gluing industry, it will produce high emissions. Light wood colour may not support the hardening on the adhesive, resulting in increasing the product's emissions (Bekhta et al., 2018; Xie et al., 2019).

Generally, many researchers accept that low wood density will result in the firmness of low adhesion. Furthermore, wood with high specific gravity will produce high adherence firmness (Sushardi & Azman, 2020). Specific gravity has a positive correlation with the parameters of wood gluing, that is known as wood stickiness. A higher density of wood will result in higher stickiness (Faye et al., 2019). The influence of wood chemical element that is strongly associated with stickiness is extractive. Extractives will inhibit the penetration of adhesives in the adhesive material (Mendes et al., 2020). The removal of these materials from the surface by the treatments, such as soaking and wetting the surface with extractive solvents will be able to enhance the stickiness (Ameen & Michniak-Kohn, 2019).

The wood chemical elements closely related to the firmness of the adhesive is through the extractive substances (Toscano et al., 2013). Extractives will inhibit adhesive penetration into the wood (Solt et al., 2019). The removal of extractive materials from the wood surface with soaking treatment and surface wetting with extractive solvents will increase the adhesive firmness (Ma et al., 2020).

Formaldehyde is a polar organic compound which can be united with water as a solvent. The lowest formaldehyde emission produced by Waru Gunung wood is suspected that the wood contains polar organic compounds that can bind free formaldehyde. It can be proved by the high levels of extractives dissolved in hot water by 10.729% than other wood species. The wood consists of low molecular weight compounds, both organic material (extractive substances) and inorganic (ash), and macromolecular that consists of polysaccharides (cellulose and hemicellulose) and lignin (Zhou et al., 2020). Polar extractive substances can bind formaldehyde and cellulose, whereas non-polar substances (Rehman et al., 2019). The wood that contained with high non-polar compounds tends to reject formaldehyde, resulting in high emissions (Candan & Akbulut, 2013; Giorio et al., 2018). The relationship between wood species and formaldehyde emissions can be seen in Figure 4.

CONCLUSION

In conclusion, Sengon, Waru Gunung, and Johar wood species have different specific gravity, wood colour, adhesive strength, and formaldehyde emissions. The higher wood specific gravity will result in higher stickiness and lower formaldehyde emissions. Wood with medium to high-density, which is Waru Gunung and Johar are acknowledged as environmentally friendly wood. Both types of wood can be used as raw material for creative industries.

REFERENCES

1. Adhikari, S., & Ozarska, B. (2018). Minimising environmental impacts of timber products through the production process "From Sawmill to Final Products." *Environmental Systems Research*, *7*(1). https://doi.org/10.1186/s40068-018-0109-x
2. Ameen, D., & Michniak-Kohn, B. (2019). Development and in vitro evaluation of pressure sensitive adhesive patch for the transdermal delivery of galantamine: Effect of penetration enhancers and crystallisation inhibition. *European Journal of Pharmaceutics and Biopharmaceutics*, *139*(April), 262–271. https://doi.org/10.1016/j.ejpb.2019.04.008
3. Basin, P. H., Science, P., Basin, H., & Basin, H. (2017). Abstracts. *Fuel and Energy Abstracts*, *58*(6), 520–594. https://doi.org/10.1016/j.fueleneab.2017.10.002
4. Bekhta, P., Krystofiak, T., Proszyk, S., & Lis, B. (2018). Surface gloss of lacquered medium density fibreboard panels veneered with thermally compressed birch wood. *Progress in Organic Coatings*, *117*(November 2017), 10–19. https://doi.org/10.1016/j.porgcoat.2017.12.020
5. Bernabei, M., Martinelli, N., & Cherubini, P. (2018). Tree-Ring Analysis on Wooden Artifacts: What Can It Tell Us? In *Nanotechnologies and Nanomaterials for Diagnostic, Conservation and Restoration of Cultural Heritage*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-813910-3.00006-9
6. Bockel, S., Mayer, I., Konnerth, J., Harling, S., Niemz, P., Swaboda, C., Beyer, M., Bieri, N., Weiland, G., & Pichelin, F. (2019). The role of wood extractives in structural hardwood bonding and their influence on different adhesive systems. *International Journal of Adhesion and Adhesives*, *91*(February), 43–53. https://doi.org/10.1016/j.ijadhadh.2019.03.001
7. Candan, Z., & Akbulut, T. (2013). Developing environmentally friendly wood composite panels by nanotechnology. *BioResources*, *8*(3), 3590–3598. https://doi.org/10.15376/biores.8.3.3590-3598
8. Dronyuk, I., Moiseienko, I., & Gregusml, J. (2019). Analysis of creative industries activities in european union countries. *Procedia Computer Science*, *160*, 479–484. https://doi.org/10.1016/j.procs.2019.11.061
9. Dupleix, A., Denaud, L. E., Bleron, L., Marchal, R., & Hughes, M. (2013). The effect of log heating temperature on the peeling process and veneer quality: Beech, birch, and spruce case studies. *European Journal of Wood and Wood Products*, *71*(2), 163–171. https://doi.org/10.1007/s00107-012-0656-1
10. Faye, M. C. A. S., Zhang, K. K., Peng, S., & Zhang, Y. (2019). Sludge dewaterability: The variation of extracellular polymeric substances during sludge conditioning with two natural organic conditioners. *Journal of Environmental Management*, *251*(September), 109559. https://doi.org/10.1016/j.jenvman.2019.109559
11. Gillerot, L., Vlaminck, E., De Ryck, D. J. R., Mwasaru, D. M., Beeckman, H., & Koedam, N. (2018). Inter- and intraspecific variation in mangrove carbon fraction and wood specific gravity in Gazi Bay, Kenya. *Ecosphere*, *9*(6). https://doi.org/10.1002/ecs2.2306
12. Giorio, C., Kehrwald, N., Barbante, C., Kalberer, M., King, A. C. F., Thomas, E. R., Wolff, E. W., & Zennaro, P. (2018). Prospects for reconstructing paleoenvironmental conditions from organic compounds in polar snow and ice. *Quaternary Science Reviews*, *183*, 1–22. https://doi.org/10.1016/j.quascirev.2018.01.007
13. Glasenapp, S., Aguilar, F. X., Weimar, H., & Mantau, U. (2019). Assessment of residential wood energy consumption using German household-level data. *Biomass and Bioenergy*, *126*(October 2018), 117–129. https://doi.org/10.1016/j.biombioe.2019.04.020
14. Haavikko, H., Kärhä, K., Hourula, M., & Palander, T. (2019). Attitudes of Small and Medium-Sized Enterprises towards Energy Efficiency in Wood Procurement: A Case Study of Stora Enso in Finland. *Croatian Journal of Forest Engineering*, *40*(1), 107–123.
15. Islam, S., & Bhat, G. (2019). Environmentally-friendly thermal and acoustic insulation materials from recycled textiles. *Journal of Environmental Management*, *251*(April), 109536. https://doi.org/10.1016/j.jenvman.2019.109536
16. Jiang, P., Khishgee, S., Alimujiang, A., & Dong, H. (2020). Cost-effective approaches for reducing carbon and air pollution emissions in the power industry in China. *Journal of Environmental Management*, *264*(February), 110452. https://doi.org/10.1016/j.jenvman.2020.110452
17. Khanali, M., Salehpour, T., & Rajabipour, A. (2020). Environmental impact assessment for ornamental plant greenhouse: Life cycle assessment approach for primrose production. *Environmental Pollution*, 115258. https://doi.org/10.1016/j.envpol.2020.115258
18. Kiroff, L. (2019). Nexus between creative industries and the built environment: Creative placemaking in inner Auckland. *Frontiers of Architectural Research*, *xxxx*. https://doi.org/10.1016/j.foar.2019.08.004
19. Kumar, V., Pathak, P., & Bhardwaj, N. K. (2020). Waste paper: An underutilised but promising source for nanocellulose mining. *Waste Management*, *102*,

281–303. https://doi.org/10.1016/j.wasman.2019.10.041

20. Ma, T., Li, L., Liu, Z., Zhang, J., Guo, C., & Wang, Q. (2020). A facile strategy to construct vegetable oil-based, fire-retardant, transparent and mussel adhesive intumescent coating for wood substrates. *Industrial Crops and Products*, *154*(September 2019), 112628. https://doi.org/10.1016/j.indcrop.2020.112628
21. Mendes, B. N., Bridi, E. C., França, F. M. G., Turssi, C. P., do Amaral, F. L. B., Basting, R. T., de Oliveira Sousa, I. M., da Silva, T. M., Gonçalves, S. E. de P., Foglio, M. A., & Basting, R. T. (2020). Polyphenol-enriched extract of Arrabidaea chica used as a dentin pretreatment or incorporated into a total-etching adhesive system: Effects on bonding stability and physical characterisation. *Materials Science and Engineering C*, *116*(May 2019), 111235. https://doi.org/10.1016/j.msec.2020.111235
22. Nguyen, T. B. V. (2018). Bamboo - The eco-friendly material - One of the material solutions of the sustainable interior design in Viet Nam. *MATEC Web of Conferences*, *193*. https://doi.org/10.1051/matecconf/201819304014
23. Oh, M., Ma, Q., Simsek, S., Bajwa, D., & Jiang, L. (2019). Comparative study of zein- and gluten-based wood adhesives containing cellulose nanofibers and crosslinking agent for improved bond strength. *International Journal of Adhesion and Adhesives*, *92*(April), 44–57. https://doi.org/10.1016/j.ijadhadh.2019.04.004
24. Petchpoung, K., Soiklom, S., Siri-anusornsak, W., Khlangsap, N., Tara, A., & Maneeboon, T. (2020). Predicting antioxidant activity of wood vinegar using color and spectrophotometric parameters. *MethodsX*, *7*, 100783. https://doi.org/10.1016/j.mex.2020.100783
25. Rehman, N., Alam, S., Mian, I., & Ullah, H. (2019). Environmental friendly method for the extraction of cellulose from Triflolium resopinatum and its characterisation. *Bulletin of the Chemical Society of Ethiopia*, *33*(1), 61–68. https://doi.org/10.4314/bcse.v33i1.6
26. Saini, B. S., & Singh, S. P. (2020). Fatigue life prediction of self compacting concrete made with recycled concrete aggregates under flexural loading. *Journal of Sustainable Cement-Based Materials*, *264*, 120233. https://doi.org/10.1080/21650373.2020.1780511
27. Solt, P., Konnerth, J., Gindl-Altmutter, W., Kantner, W., Moser, J., Mitter, R., & van Herwijnen, H. W. G. (2019). Technological performance of formaldehyde-free adhesive alternatives for particleboard industry. *International Journal of Adhesion and Adhesives*, *94*(April), 99–131. https://doi.org/10.1016/j.ijadhadh.2019.04.007
28. Sushardi, M., & Azman, M. N. A. (2020). Utilisation of wood industry waste as raw material for cement boards production. *International Journal of Advanced Science and Technology*, *29*(4 Special Issue), 1897–1902.
29. Teuber, L., Osburg, V., Toporowski, W., Militz, H., Krause, A., Ecology, F., Biology, W., & Products, W. (2016). *Wood polymer composites and their contribution to cascading utilisation Keywords :*
30. Toscano, G., Riva, G., Foppa Pedretti, E., Corinaldesi, F., Mengarelli, C., & Duca, D. (2013). Investigation on wood pellet quality and relationship between ash content and the most important chemical elements. *Biomass and Bioenergy*, *56*(0), 317–322. https://doi.org/10.1016/j.biombioe.2013.05.012
31. Werdin, J., Fletcher, T. D., Rayner, J. P., Williams, N. S. G., & Farrell, C. (2020). Biochar made from low density wood has greater plant available water than biochar made from high density wood. *Science of the Total Environment*, *705*, 135856. https://doi.org/10.1016/j.scitotenv.2019.135856
32. Xie, J., Ping, H., Tan, T., Lei, L., Xie, H., Yang, X. Y., & Fu, Z. (2019). Bioprocess-inspired fabrication of materials with new structures and functions. *Progress in Materials Science*, *105*(May), 100571. https://doi.org/10.1016/j.pmatsci.2019.05.004
33. Zhang, Y., Jiang, J., Bai, Y., Liu, J., Shao, H., Wu, C., & Guo, Z. (2019). A fractional mass transfer model for simulating VOC emissions from porous, dry building material. *Building and Environment*, *152*(January), 182–191. https://doi.org/10.1016/j.buildenv.2019.01.053
34. Zhou, X., Moghaddam, T. B., Chen, M., Wu, S., & Adhikari, S. (2020). Biochar removes volatile organic compounds generated from asphalt. *Science of the Total Environment*, *745*(27), 141096. https://doi.org/10.1016/j.scitotenv.2020.141096