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Bio-based Materials for Moisture-Resistant Refugee Housing: A Comparative Study of Cork, Timber and Bamboo

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Abstract

This experimental study examines the moisture absorption behavior of three bio-based construction materials, cork, timber, and bamboo, to determine their feasibility for use in flood-prone environments across refugee settlements. Globally, the construction industry is responsible for nearly 37% of greenhouse gas emissions, primarily due to the use of carbon-intensive materials. Climate change has not only driven extreme weather but has also disproportionately affected vulnerable populations, forcing them to relocate due to environmental instability. Refugee complexes require sustainable materials that can withstand extreme climate conditions while simultaneously providing a safe shelter for displaced communities. Bio-based materials, made from fibers and engineered wood, in contrast to inorganic mineral-based materials, are renewable, can store carbon, and offer other benefits, making them a viable alternative to carbon-intensive materials that contribute heavily to global warming. Material samples measuring 6 x 3 x ¼ inches were submerged in water over several days to measure moisture content. The findings suggest that bamboo and timber are better suited to flood-prone environments than cork, due to their moisture-resistance properties. By reducing the use of carbon-intensive materials in refugee shelters, it is possible to lower carbon emissions, promote climate-resilient materials, and support United Nations Sustainable Development Goals 9 and 11.

Keywords
Materials Science, Construction Materials, Bio-Based Materials, Moisture Absorption, Refugee Housing

1. Introduction
1.1 Environmental Impact of Current Construction Materials
The global construction industry accounts for 37% of greenhouse gas emissions, being the largest sector to contribute.(UNEP, 2023) Current construction materials, such as concrete, steel, cement, and aluminum, are major drivers of climate pollution and must be replaced because they have enormous environmental impacts.(Bataille, 2023) These materials deplete other natural resources, such as sand and gravel, leading to waste generation in the materials production industry.(Scrivener and Shell, 2023) When used in construction, these materials are often mixed with chemical sealants and other protective practices, which release several pollutants that mix with indoor air.(Spellman, n.d.) Roughly ⅓ of that percentage comes from embodied energy, which involves manufacturing and installing these materials, while ⅔ is from operational energy for heating, cooling, and electricity use.(UNEP, 2023) Steel and concrete are used in the manufacturing of several building projects, and, as the two most carbon-intensive materials, they account for approximately 16% of global greenhouse gas emissions. By 2050, it is expected that embodied carbon levels will be as high as operational carbon levels for buildings, as there is no regulation driving embodied carbon down nor any incentives to use less carbon-intensive materials. By researching the properties of various bio-based and low-carbon construction materials, there may be a chance to decrease carbon and greenhouse gas contributions, and in turn, support the United Nations Sustainable Development Goals.
Traditional construction materials such as concrete and steel require energy-intensive extraction processes, which

release large amounts of CO2 into the atmosphere, whereas bio-based alternatives like cork, timber, and bamboo require less energy to farm, produce, and procure.(UNEP, 2023) By choosing more sustainable options for construction, building efforts can be directly tied to SDG 9: Industry, Innovation, and Infrastructure, as well as SDG 11: Sustainable Cities and Communities, by promoting low-emission infrastructure, durable buildings, and long-term practices that uphold environmental stability. This research advances efforts to uphold these SDGs by highlighting the importance of material selection and its role in lowering emissions while enhancing infrastructure.

By decreasing emissions within the material production and selection stage, low-carbon materials will play a critical role in achieving lower carbon emissions from this industry, while also addressing concerns about climate change and futuristic cities (Environmental Protection Agency, 2013).

1.2 Bio-Based Materials

When choosing materials for construction, moisture content is often taken into consideration with regard to the climate and weather patterns. Moreover, measuring the moisture content of construction materials is crucial to ensure structural integrity and strength (Environmental Protection Agency, 2013). If not properly treated or measured, excess moisture can lead to material decay, mold, and unsafe air quality. Some materials may even corrode in moist environments, which can lead to poorer health quality, invasive bacteria, and the chance of contamination (Environmental Protection Agency, 2013). Materials that absorb too much water often degrade faster, so engineers need to select specific materials that are best suited for specific climates. Instead, cork, timber, and bamboo are all bio-based materials that are being tested as viable climate-resilient alternatives and increasingly being used as sustainable alternatives to current construction materials (Dexter and Davey, 2023). These choices may be able to reduce long-term deterioration and design more sustainable and long-lasting buildings. Moisture also tends to go hand in hand with insulation, where wet materials conduct more heat and reduce insulation capabilities, and vice versa.(Dafico et al., 2023) Measuring the moisture properties and performance of various bio-based materials is crucial to predicting the future performance of certain materials and improving living safety,(Dafico et al., 2023) thereby contributing to research in a newly developing field of bio-based materials.

Cork oak is found throughout Southwestern Europe and Northwestern Africa, specifically in nations such as Portugal, Spain, France, Italy, Algeria, Morocco, and Tunisia. It is a sustainable material as its farming mechanism eliminates the need to cut down an entire tree, and the cork bark of one tree can be harvested up to sixteen times.

Timber is usually sourced from the Eastern United States and Scandinavian regions and can easily be replenished in well-managed forests. It is a biodegradable material that releases carbon dioxide and water back into the atmosphere once decomposed. Bamboo is sourced from regions in Asia, and tends to mature in three to five years, but does not need to be replanted because the root remains intact after harvest (Bamboo, 2021).

1.3 Climate Vulnerability of Refugee Complexes

Refugee complexes were selected as the focus of this research due to their long-standing vulnerability to climate change and environmental instability. These settlements are often located in regions that experience extreme weather conditions, such as flooding, prolonged rainfall, and severe weather fluctuations. Limited resources, rapid population growth, and temporary solutions increase susceptibility to environmental damage, as structures are not built to be permanent shelters. Moisture resistance, durability, and sustainability directly impact the safety and living conditions of the people in these complexes. As a result, the selection of sustainable construction materials is critical to ensuring structurally sound shelters for the millions of refugees who settle in these camps.

In refugee complexes, the most common materials used are plastic sheets, PVC coverings, and corrugated metal sheets (Spellman, 2025). These materials have traditionally been used due to easy assembly and relatively lower prices, but they offer limited resistance to severe weather conditions and climate change (Team, 2025). Many refugee complexes are located in relatively humid regions, and yet the chosen materials are not safe to withstand various temperature changes. When exposed to prolonged periods of water, plastic sheets and metal coverings often lead to chemical degradation, where carcinogenic substances are released through rust and corrosion.(Team, 2025) These materials are not biodegradable, and they fragment into smaller, harmful particles that persist in the environment and affect the overall air quality.(Team, 2025) As a result, many shelters in refugee complexes are not sustainable and are constructed with materials that deteriorate rapidly over time without providing adequate protection in cases of rain, humidity, and other extreme weather conditions.

The three refugee facilities being examined in this study are located in Africa and Asia. They were specifically selected as they are among the largest refugee complexes in the world, collectively house millions of people, and constantly face climate-related risks, demonstrating the need for proper infrastructure to be put in place (UNHCR, 2023). First, the Dadaab Refugee Complex in Northeastern Kenya (Figure 1) is located in a semi-arid region but often faces flash floods and severe droughts. Shelters are built with a combination of wood sticks, mud, cloth, and iron sheeting (Public Broadcasting Service, 2015). These structures often involve digging into the ground with improper materials, which can accumulate stagnant water that, in turn, spreads bacteria and worsens structural integrity (UNHCR, 2025).

Figure 1. A picture of the temporary, tarpaulin-based shelters in the Dadaab Refugee Complex (Public Broadcasting Service, 2015)

These shelters highlight the vulnerability of current materials to flooding and poor drainage, reinforcing the need for more durable, moisture-resistant alternatives. The Za'atari Camp (Figure 2) in Jordan is located in a cold, dry desert that experiences extreme conditions. Temperatures in summer reach up to 104 F, while winters are wet and cold with extreme rain and prolonged floods (Dunmore, 2015). Shelters here originated as tents and have since been converted into caravans; however, the caravans now require extensive repairs due to damaged walls. Additionally, the metal sheeting tends to overheat in the summer, causing structural changes and the possibility of hazardous fumes (Mercy Corps, 2015).

Figure 2. A picture of the modular, caravan-based structures in the Za'atari Camp (Carlisle, 2022) These structures demonstrate how extreme weather conditions, including heat and rainfall, contribute to material degradation over time.

Finally, the Kutupalong Camp (Figure 3), also known as Cox's Bazar, in Bangladesh, is prone to heavy rainfall during the monsoon season, and shelters are susceptible to storm damage and severe floods (Saltmarsh, 2018). Shelters in this camp use bamboo as a load-bearing support, whereas roofs and coverings are made with polyethylene sheets (Saltmarsh, 2018). The materials tested in this research paper are readily available in continents like Africa and Asia, where major refugee complexes exist, making them a good alternative to current materials. This example (Figure 3) illustrates the partial use of bio-based materials like bamboo, though structural limitations still exist due to moisture exposure.

Figure 3. A picture of the temporary shelters at Cox's Bazar, constructed with bamboo and plastic sheeting (Shohag, 2023).

2. Methods

2.1 Materials

- Pinless Moisture Meter
- 9 Blocks of Cork (1/4 x 6 x 3)
- 9 Blocks of Timber (1/4 x 6 x 3)
- 9 Blocks of Bamboo (1/4 x 6 x 3)
- Fishing Weights
- Aluminum Foil Trays
- Paper Towels

2.2 Hypothesis

Since bamboo and timber are denser and contain more fibrous material than cork, they should absorb water rapidly at first and then reach moisture balance, resulting in a lower overall moisture percentage and minimal change over time compared to cork, which is made up of air-filled bark.

2.3 Methodology

This study uses an experimental research design to evaluate the moisture absorption properties of three increasingly used bio-based construction materials: cork, timber, and bamboo. The objective of this research experiment is to compare the moisture percentage intake over time for these materials to assess the feasibility of use in various climates. Moisture absorption was selected as a variable to test material durability, structural stability, and long -term performance given various climate conditions. All three materials, corkboard, engineered timber, and bamboo sheets, are increasingly being used as sustainable alternatives to conventional construction materials. Cork is primarily sourced from Southwest European regions, and timber is sourced and utilized in North American construction. In contrast, bamboo is used primarily in Asian regions due to proximity, renewability, and structural properties.

The standardized material size of 6 x 3 x 1/4 inches was chosen to ensure consistency in results across all materials. Using near-identical dimensions across all samples and trials ensured that moisture intake could be calculated without size acting as a separate variable to consider. The ¼ inch depth was selected to ensure that the water could completely penetrate the full thickness of each material during the soaking process, rather than simply staying only on the surfaces of the materials. This measurement is also taken into account with current construction materials used in floorings and finishes, so results are still applicable to real-world scenarios.

In the experiment, there were no protective coatings, sealants, or additional chemical treatment applied to the materials, allowing the experiment to measure the natural properties. Moisture content was measured using a digital wood moisture meter, which determines moisture percentage levels by measuring electrical resistance within the material. The same wood moisture meter was used to collect data for all trials and materials to maintain consistency and minimize error.

Each material was tested through three trials to reduce error and standardize results. The samples were exposed to a controlled environment with a temperature of 68 °F and were placed in identical containers with equal volumes of water. The moisture percentage measurements were recorded at 3 different time intervals to reflect various real-world scenarios.

- 24 hours (1 day): Slightly humid climate, a full day of rainfall
- 96 hours (4 days): Tropical storm, short-term flooding
- 168 hours (7 days): Hurricane flooding, extremely humid climate, heavy rainfall

3. Results and Discussion

Moisture content results were recorded from cork (c), bamboo (b), and timber (t) under dry and wet conditions across three trials and four different time intervals, all conducted using a softwood moisture meter (Table 1). Under dry conditions, cork samples consistently had low moisture content, ranging from a moisture content of 3.90% to 4.60%. While there was minimal variation in moisture content across trials, as the days went on, the percentage of moisture in the cork increased, indicating a positive correlation with the hypothesis. Bamboo samples had a higher dry moisture content than cork, with percentage values between 12.70% and 13.30%. The values remained relatively consistent within trials, and across the span of one, four, and seven days, they tended to absorb moisture at first and retain solely that value for the remainder of the experiment. Timber samples had the greatest variability in dry conditions, with moisture percentages ranging from 8.10% to 13.90%. Given that cork had the greatest spread of values for initial conditions, the spread continued throughout the experiments for each day. However, timber exhibited properties similar to bamboo, absorbing most water at first and then tending to level out, as shown in Figure 4.

Table 1. Recorded moisture content from cork (c), bamboo (b), and timber (t) under dry and wet conditions across three trials and four different time intervals, all conducted using a softwood moisture meter.

Material	Trial	Day	Dry %	Wet %
Cork	T1	1	4.20%	39.40%
Cork	T2	1	4.60%	48.30%
Cork	T3	1	4.20%	34.30%
Cork	T1	4	4.20%	52.70%
Cork	T2	4	4.00%	53.40%
Cork	T3	4	3.90%	53.60%
Cork	T1	7	4.40%	55+
Cork	T2	7	4.30%	55+
Cork	T3	7	4.30%	55+
Bamboo	T1	1	13.00%	30.40%
Bamboo	T2	1	13.20%	31.40%
Bamboo	T3	1	12.90%	30.70%
Bamboo	T1	4	13.30%	31.80%
Bamboo	T2	4	13.10%	32.10%
Bamboo	T3	4	12.90%	31.80%

Bamboo	T1	7	12.70%	32.30%
Bamboo	T2	7	13.00%	32.70%
Bamboo	T3	7	12.90%	32.60%
Timber	T1	1	12.50%	24.80%
Timber	T2	1	11.90%	27.80%
Timber	T3	1	8.90%	31.40%
Timber	T1	4	11.00%	26.90%
Timber	T2	4	8.10%	32.90%
Timber	T3	4	13.90%	27.20%
Timber	T1	7	9.00%	28.30%
Timber	T2	7	9.50%	32.90%
Timber	T3	7	12.90%	34.50%

C stands for Cork, B stands for Bamboo, and T stands for Timber. T1, T2, and T3 indicate which trial the percentage is taken from. The numbers at the end (1, 4, and 7) indicate how many days each piece of wood had been submerged. Cork had the lowest dry % and highest wet % compared to timber and bamboo.

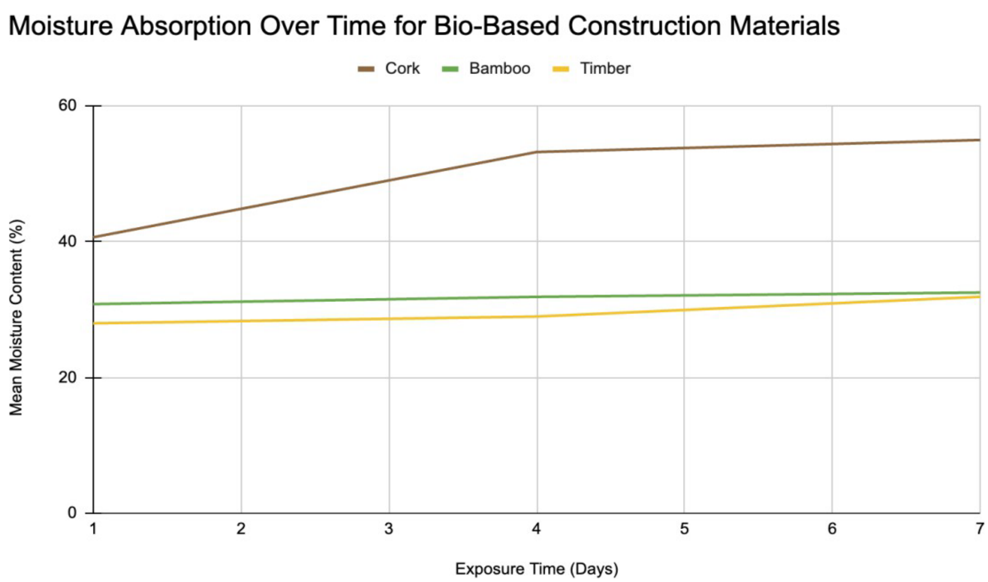

Figure 4. A graph measuring the average moisture absorption for each respective material over the course of 7 days.

Cork had the highest mean moisture content compared to bamboo and timber.
The results (Table 2) indicate the differences in absorption and moisture content behavior for the various materials in two different conditions, with cork having the lowest dry moisture level and higher wet moisture absorption, bamboo having relatively consistent values throughout, and timber having a greater variability in moisture content percentages across trials. All materials were suitable for Dry/Arid Climates. Bamboo was the most suitable across all climate conditions and timber was intermediate between cork and timber.

Table 2. Transparency index of suitable settings for each respective bio-based material.

Climate Condition	Cork	Bamboo	Timber
Dry / Arid Climate	Suitable	Suitable	Suitable
Short-Term (1 Day) Water Exposure	Unsuitable	Suitable	Suitable (Inconsistent)
Medium-Term (4 Days) Water Exposure	Unsuitable	Suitable	Suitable (Inconsistent)
Long-Term (7 Days) Water Exposure	Unsuitable	Suitable	Suitable (Inconsistent)

3.1 Limitations

Despite a relatively controlled environment, the experiment had some limitations and sources of error that may have impacted on the accuracy of the results. One limitation was that, although the material thickness of ¼ inch was standardized, the dimensions of 6 x 3 inches were slightly altered between the materials. Bamboo, which initially was procured as a 12 x 18-inch board, proved to be more difficult to cut due to its tightly bound grass-like structure. This alteration in dimensions may have induced variations in internal density, potentially affecting the absorption percentages taken by the moisture meter. Another limitation was that the digital moisture meter had four settings: drywall, masonry, hardwood, and softwood. Since cork, bamboo, and timber do not fall under the same category, the measurements were taken under the softwood setting, given the most similar properties. Cork is considered an air-filled bark, and bamboo is known as a grass; neither perfectly fits under the category of a softwood. The moisture meter used in this experiment relied on electrical resistance for measurements, so material density and the composition of the materials may have yielded imprecise results.

With respect to the softwood setting, the measurements had a limit of 55% moisture content. Three cork samples over the course of 168 hours had exceeded this limit, resulting in limited readings rather than precise measurements. Given this limitation, it was particularly difficult to calculate the actual moisture percentage in cork after the given time. Additionally, all materials remained untreated with no sealants or protectants applied for research purposes. In the real world, construction materials often use such chemicals for strengthening properties, so there may be slightly varied results if the materials are treated. Finally, although the experiment was conducted in a relatively controlled indoor environment, outdoor temperatures had been fluctuating over the course of the experiment and may have impacted the indoor conditions.

3.2 Recommendations

Based on the results of this experimental study, bamboo and timber are more suitable bio-based construction materials for use in flood-prone environments, specifically in refugee shelter construction. Both materials had the ability to absorb water initially and stabilize over time, showing a greater resistance to moisture absorption than cork. Bamboo sheets showed the most consistent moisture content across all the trials, and it may be a strong material for structural purposes in regions with heavy rainfall and high humidity. In refugee complexes with similar climates to those of the Dadaab, Za'atari, and Kutupalong camps, bamboo and timber should be explored as a structural material to protect against future weather advisories. Cork, with a known application as an insulation material, is better suited for that purpose rather than as a structural material due to its high moisture absorption values. Future research can expand on this study by testing the treated and chemically-strengthened versions of these materials to reflect real-world construction materials. Given the limitations of the digital moisture meter, using material-specific meters for measurements may yield more accurate results, especially for bamboo and cork. In addition, incorporating waterproofing sealants and elevated structural designs, such as stilts, may enhance the durability of these materials and shelters in flood-prone environments. These improvements in future studies would yield more precise conclusions for sustainable refugee shelter design.

4. Conclusion

This study measured the moisture absorption behavior of cork, timber, and bamboo to determine their feasibility as sustainable construction materials, with results showing that cork absorbed the greatest amount of water while bamboo and timber stabilized after initial water intake. These findings suggest that timber and bamboo may be better suited for construction in climates where high humidity and floods are frequent. Overall, the use of these materials in construction could improve durability, affordability, and sustainability while aligning with the United Nations Sustainable Development Goals.

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References

Bamboo, G. “How Fast Does Bamboo Grow?” *Rebo Bamboo*, 2021. https://www.rebo-bamboo.com/news/how-fast-does-bamboo-grow

Bataille, C. “Decarbonizing Steel and Cement,” *Center on Global Energy Policy at Columbia University SIPA (CGEP)*, 2023. https://www.energypolicy.columbia.edu/decarbonizing-steel-and-cement/

Carlisle, L. “Jordan's Za'atari Refugee Camp: 10 Facts at 10 Years,” *UNHCR*, 2022. https://www.unhcr.org/news/stories/jordans-zaatari-refugee-camp-10-facts-10-years

“Cork Oak,” *Rainforest Alliance*, 2023. https://www.rainforest-alliance.org/species/cork-oak/

Dafico, L. C. M., Barreira, E., Almeida, R. M. S. F., and Vicente, R. “Machine Learning Models Applied to Moisture Assessment in Building Materials,” *Construction and Building Materials*, Vol. 405, p. 133330, 2023. https://doi.org/10.1016/j.conbuildmat.2023.133330

Dexter, J., and Davey, M. “Low-Carbon Building Materials: Designers Discuss Alternative Options,” *Stantec*, 2023. https://www.stantec.com/en/ideas/topic/sustainable-resilient-design/low-carbon-building-materials-designers-discuss-alternative-options

Dunmore, C. “Winter Storms Bring More Hardship to Refugees in Jordan's Za'atari Camp,” *UNHCR*, 2015. https://www.unhcr.org/news/stories/winter-storms-bring-more-hardship-refugees-jordans-zaatari-camp

Environmental Protection Agency. “Moisture Control Guidance for Building Design, Construction and Maintenance,” *United States Environmental Protection Agency*, pp. 1–144, 2013. https://www.epa.gov/sites/default/files/2014-08/documents/moisture-control.pdf

Mercy Corps. “Syrian Refugees Brave Brutal Summer Conditions,” *Mercy Corps*, 2015. https://www.mercycorps.org/blog/syrian-refugees-summer-conditions

Pine, A. T. “8 Reasons Why Australian Timber Is Sustainable Material to Use,” *Australian Treated Pine*, 2024. https://www.atpine.com.au/reasons-why-timber-is-sustainable-material/

Public Broadcasting Service. “Photos: Pumping Iron and Making Art While Stuck in the World's Largest Refugee Camp,” *PBS NewsHour*, 2015. https://www.pbs.org/newshour/world/photos-worlds-largest-refugee-camp

Saltmarsh, M. “Rohingya Refugees Race to Fix Up Shelters as Monsoon Looms,” *UNHCR Africa*, 2018. https://www.unhcr.org/africa/news/stories/rohingya-refugees-race-fix-shelters-monsoon-looms

Scrivener, K., and Shell, S. “How Low-Carbon Cement Can Benefit Emerging Economies and the Planet,” *ClimateWorks Foundation*, 2023. https://www.climateworks.org/blog/how-low-carbon-cement-can-benefit-emerging-economies-and-the-planet/

Shohag, A. A. M. “Finding Hope Away from Home: Supporting Displaced Populations in the World's Largest Refugee Camp,” *Population Council*, 2023. https://popcouncil.org/insight/finding-hope-away-from-home-supporting-displaced-populations-in-the-worlds-largest-refugee-camp/

Team, Y. “Natural Building Material Could Be Used for Safer Refugee Housing,” *Yale Climate Connections*, 2025. https://yaleclimateconnections.org/2025/03/natural-building-material-could-be-used-for-safer-refugee-housing/

UNEP. “Building Materials and the Climate: Constructing a New Future,” *UN Environment Programme*, 2023. https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future

UNHCR. “Guidelines for Flood Resilient Humanitarian Shelters,” *United Nations High Commissioner for Refugees*, 2025. https://www.unhcr.org/sites/default/files/2025-06/guidelines-for-flood-resilient-humanitarian-shelters.pdf

UNHCR. "Inside the World's Five Largest Refugee Camps," *UNHCR*, 2023. https://www.unrefugees.org/news/inside-the-worlds-five-largest-refugee-camps/

Biography

Varsha Ayalasomayajula is a high school senior at the Madeira School in Virginia. She is interested in pursuing a double major in materials science & engineering and economics in college. Her work on designing climate-resilient classrooms for refugee youth and climate-displaced populations inspired this research article on bio-based materials.