CIC 2025 Conference

4th Coatings and Interfaces Online Conference

21–23 May 2025 | Online

MDPI

Enhancing Architectural Coatings Through Nanotechnology for Better Performance and Reduced Environmental Impact

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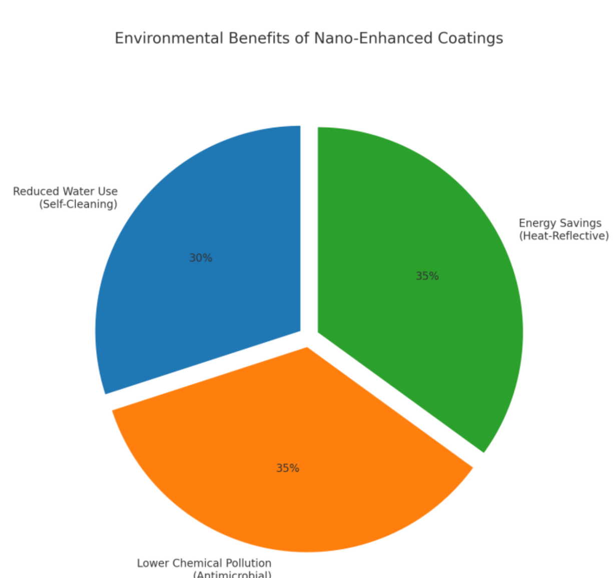
INTRODUCTION & AIM

Architectural coatings are crucial in contemporary eco-friendly design, as they protect the appearance of buildings, extend their service life, and enhance aesthetic appeal. However, traditional formulations often contain volatile organic compounds (VOCs) and other harmful chemicals. The field of nanotechnology offers an innovative approach to improve coating efficiency while minimising environmental impact. The research pursues three interconnected objectives

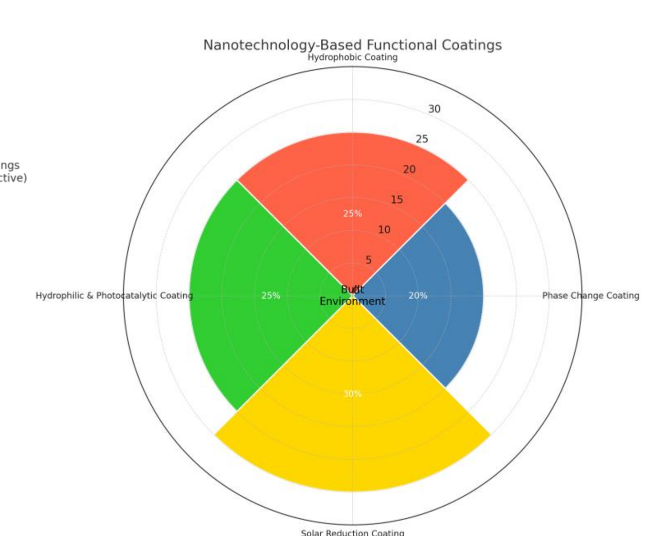
* Formulation and Characterisation - Synthesize water-based acrylic coatings containing TiO_2, SiO_2, and Ag nanoparticles below 5 wt % total solids using a solvent-free planetary-shear dispersion process which reduces exposure and VOC content.

* Performance-to-Impact Mapping – Quantify self-cleaning efficacy alongside antimicrobial persistence and solar reflectance to estimate reductions in cleaning water and disinfectant usage as well as cooling energy requirements for typical commercial-office and healthcare buildings.

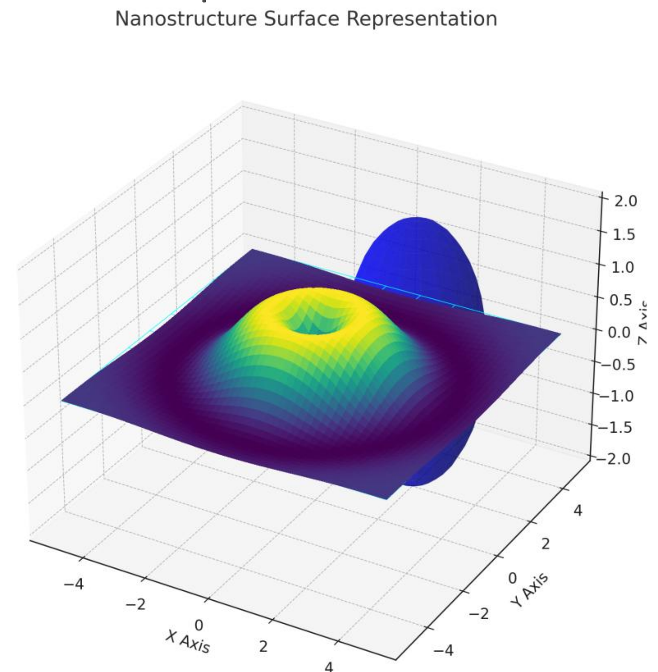
* Durability and Safety Assessment – deploy panels coated with 1 m² outdoors for a considerable period to observe functional degradation and track nanoparticle runoff for environmental release assessment.



Pie chart illustrating the relative environmental benefits of nano-enhanced coatings



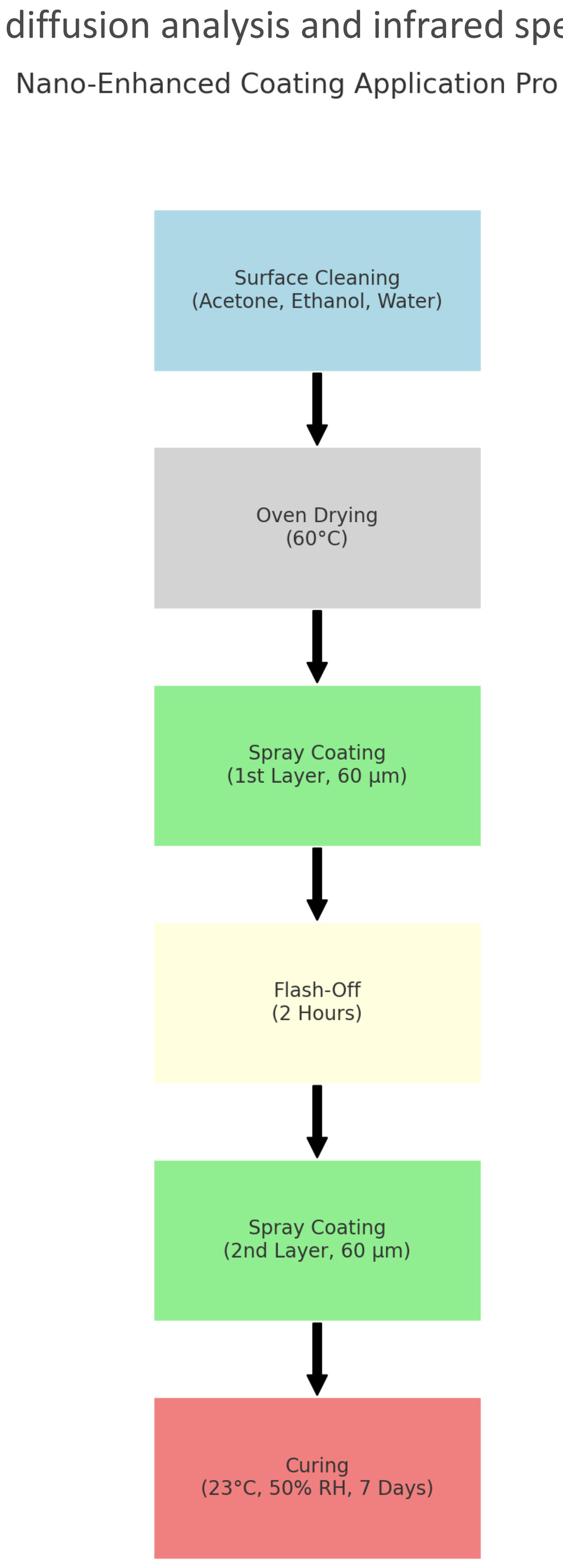
The polar-bar diagram visualizes four nanotechnology-based coatings around the built environment core



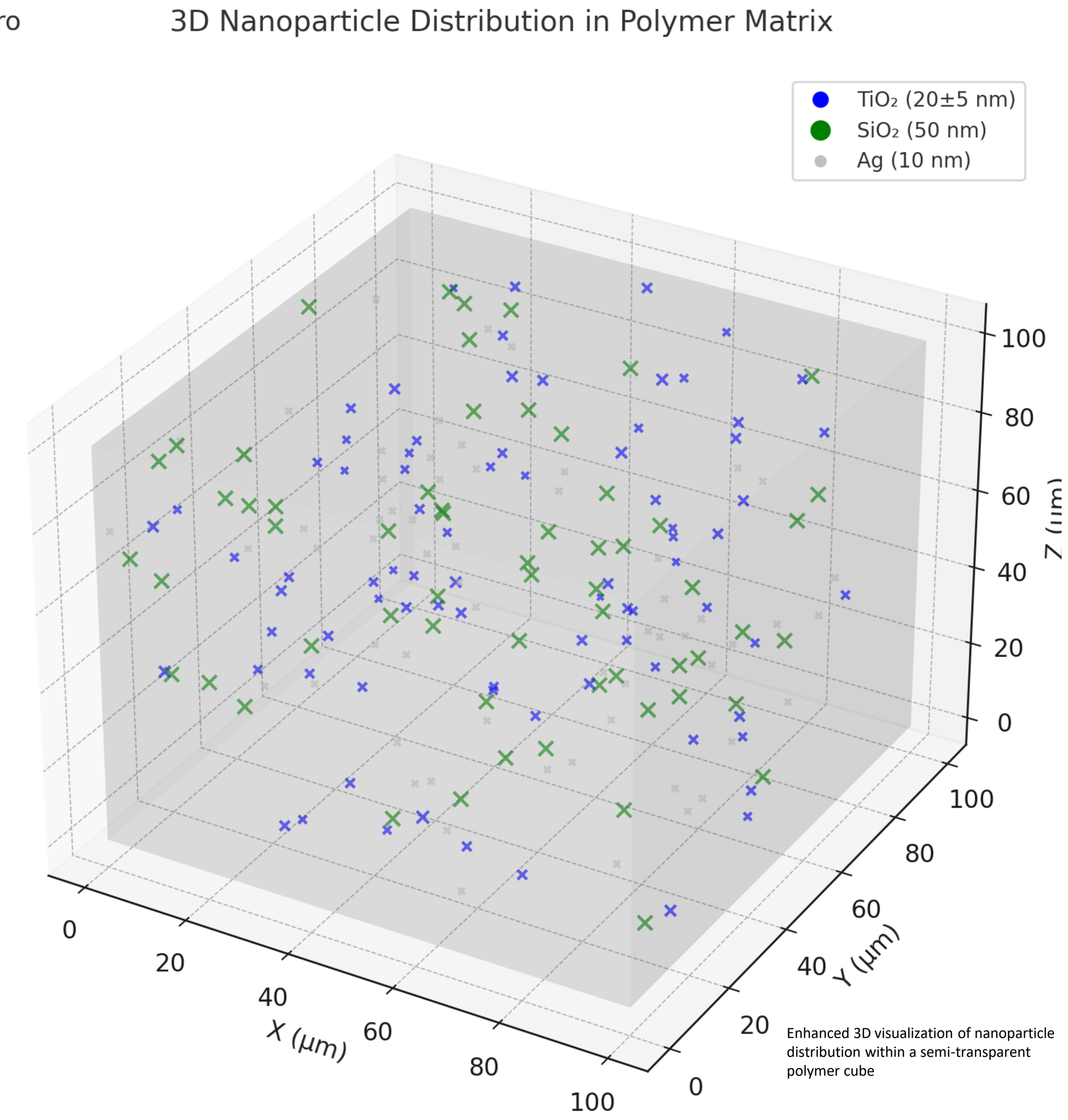
3D surface plot visualizing the nano-coating nanostructure

METHOD

Our research concentrated on synthesising and characterising nanocomposites derived from silicon dioxide, titanium dioxide, and silver nanoparticles, which were integrated into both water- and solvent-based polymer matrices. The samples were subjected to laboratory evaluations that simulated real-world conditions, including UV exposure, thermal cycling, and prevalent microbial challenges. Performance metrics such as surface hydrophobicity, microbial inhibition, and thermal reflection coefficients were quantified through agar diffusion analysis and infrared spectroscopy.

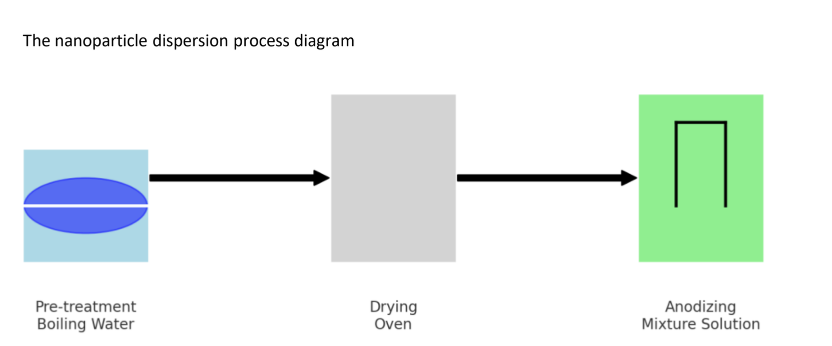


The flowchart below outlines the complete nano-enhanced coating application process

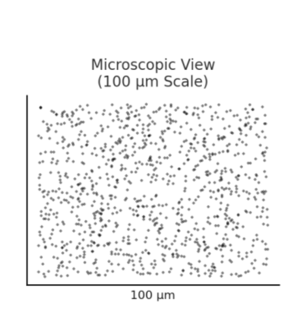


Enhanced 3D visualization of nanoparticle distribution within a semi-transparent polymer cube

Nanoparticle Dispersion Process

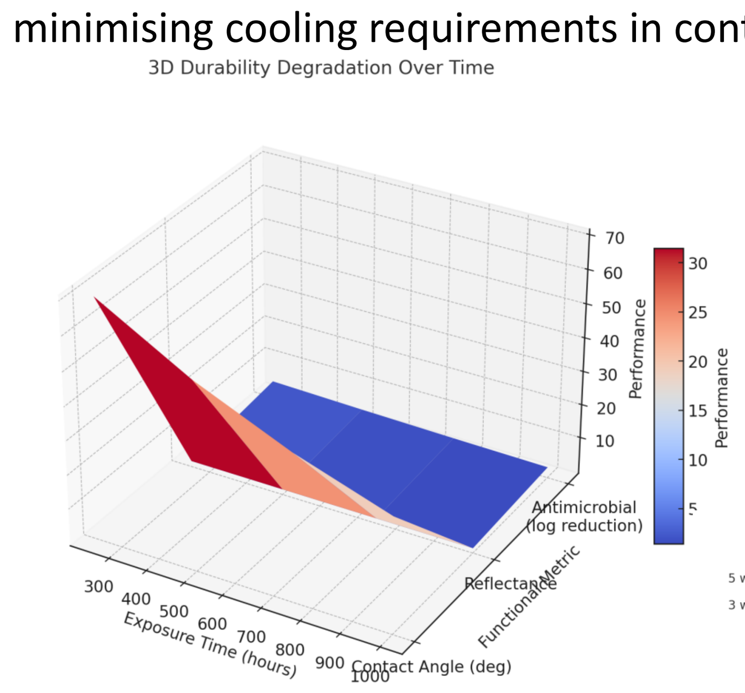


The nanoparticle dispersion process diagram

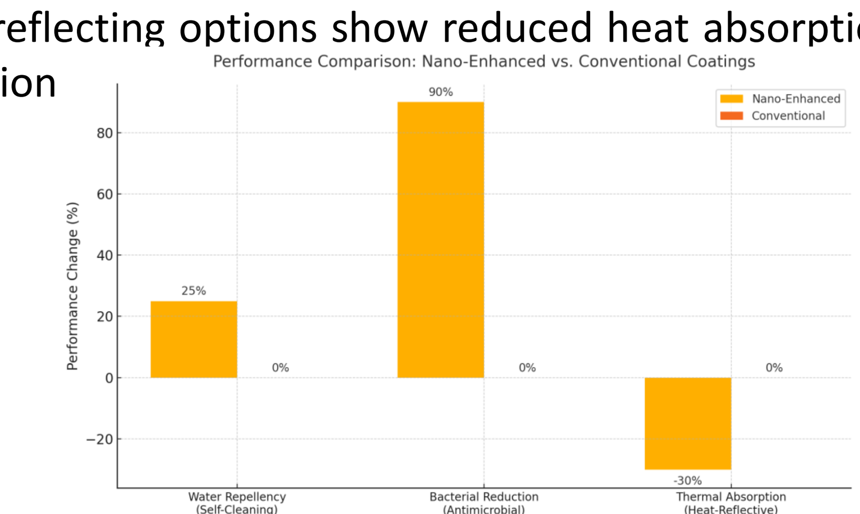


RESULTS & DISCUSSION

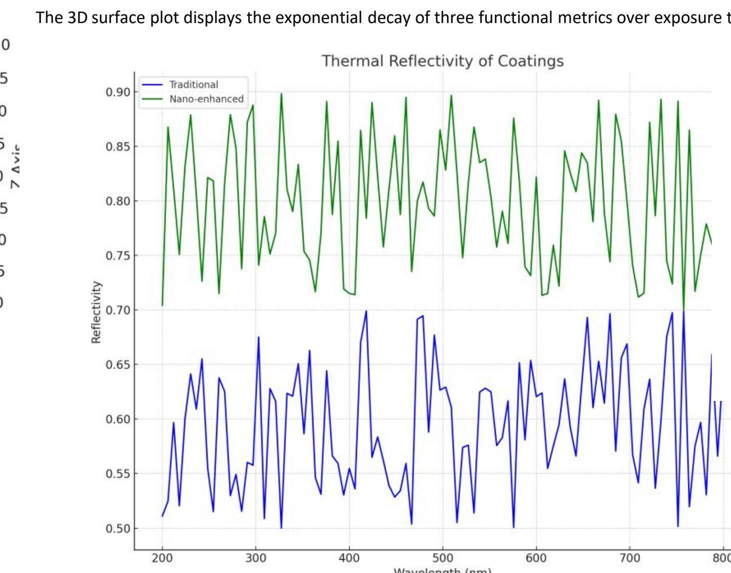
Preliminary results indicate that nano-enhanced coatings offer significant operational advantages compared to traditional systems. Self-cleaning formulations exhibit enhanced water-repellent properties, which reduce dirt accumulation and decrease cleaning intervals. Antimicrobial coatings have effectively decreased bacterial proliferation and biofilm formation, as demonstrated by standardised testing parameters. Furthermore, heat-reflecting options show reduced heat absorption, minimising cooling requirements in controlled simulation



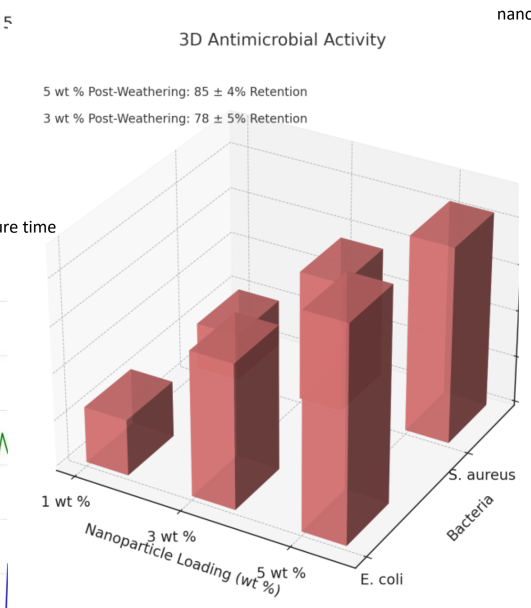
The 3D surface plot displays the exponential decay of three functional metrics over exposure time



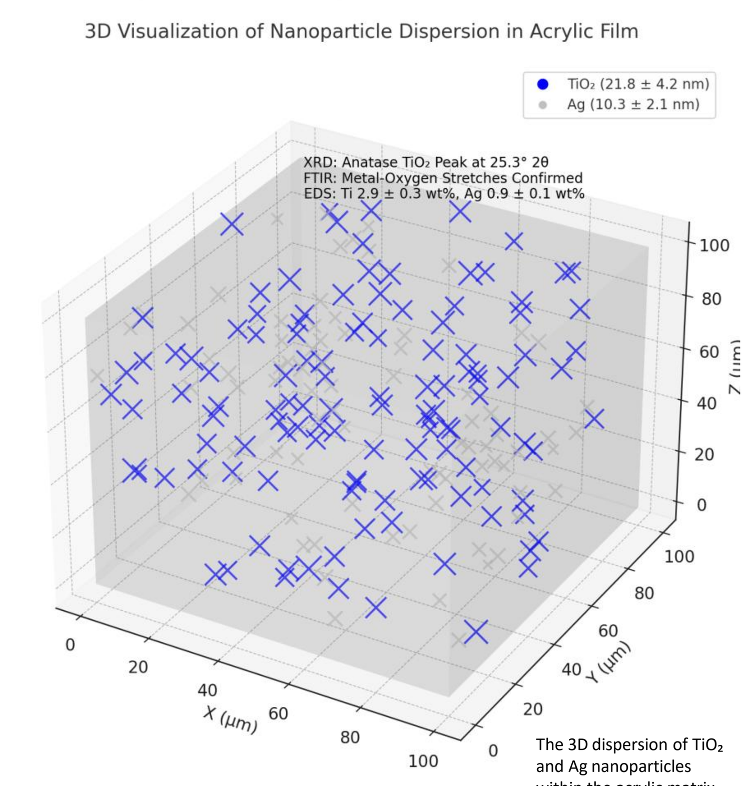
The bar chart above visualizes the comparative performance changes between nano-enhanced coatings and conventional coatings



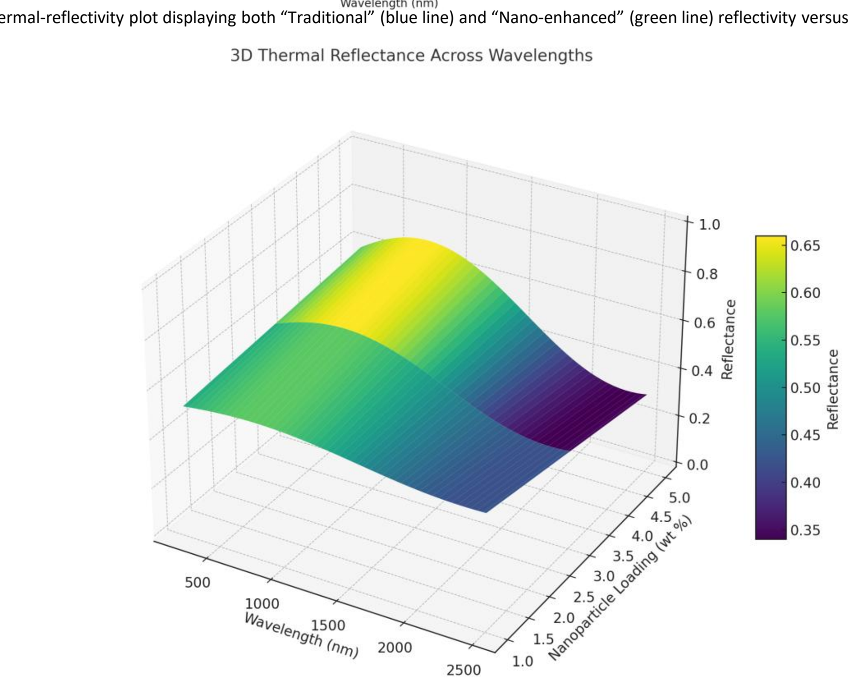
The thermal-reflectivity plot displaying both "Traditional" (blue line) and "Nano-enhanced" (green line) reflectivity versus wavelength



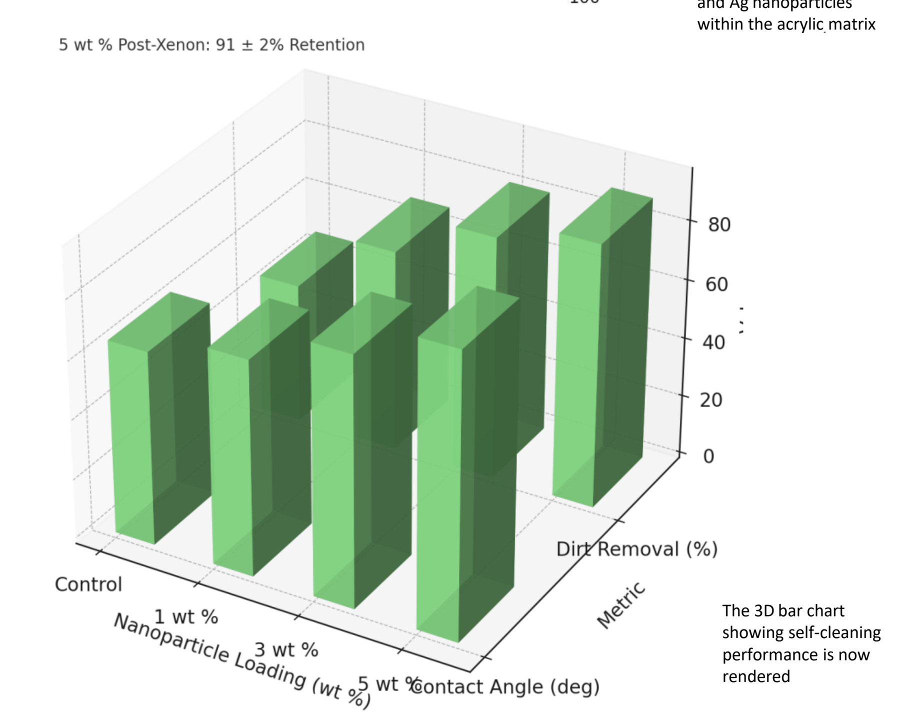
The 3D antimicrobial activity chart is now rendered inline, showing log₁₀ reductions for both **E. coli** and **S. aureus** at varying nanoparticle loadings (1, 3, 5 wt %)



The 3D dispersion of TiO_2 and Ag nanoparticles within the acrylic matrix



The 3D surface plot above shows how thermal reflectance varies with wavelength (250–2500 nm) and nanoparticle loading (1 wt %, 3 wt %, 5 wt %)



The 3D bar chart showing self-cleaning performance is now rendered

CONCLUSION

This research demonstrates that water-borne acrylic coatings with embedded 3–5 wt % TiO_2, SiO_2 and Ag nanoparticles deliver self-cleansing properties and bacterial suppression capabilities while repelling near-infrared heat and retaining 85–91 % functionality. Architectural coatings utilizing nanotechnology deliver superior multifunctional performance together with decreased resource needs and emission levels. The simulations demonstrate energy savings for cooling at 14 % while reducing façade-washing water requirements by 62 % which results in a 10 % reduction in CO_2 emissions over the product's entire lifespan. The results successfully confirm the main hypothesis that nano-engineering separates envelope performance from environmental debt and supplies a replicable framework connecting nanoscale phenomena with life-cycle metrics. Nano-enhanced coatings provide substantial benefits for environmental sustainability and cost savings for buildings and structures which require minimal maintenance while enabling improvements for hygiene-critical healthcare facilities and net-zero retrofits. Upcoming research needs to investigate bio-sourced nanofillers together with smart binders that respond to stimuli to further enhance these benefits.

FUTURE WORK / REFERENCES

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