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Research Paper

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From brass to brilliance: Frugal innovation for safer public spaces

This study explores the application of brass, noted for its cost-effective antimicrobial properties, as a frugal innovation to enhance public sanitation in high-traffic public health settings such as hospitals and public transport systems. Underpinned by the principles of frugal innovation - resource efficiency, affordability, accessibility, and sustainability, this research assesses the effectiveness and economic viability of various brass applications for microbial control on high-touch surfaces. Through an exploratory review of the literature, this study identifies that brass applications not only reduce the need for frequent sanitation but also ensure durability and long-term effectiveness in public spaces. Findings highlight that integrating brass in public infrastructure significantly lowers infection rates and healthcare costs, aligning with frugal innovation's focus on maximizing value with minimal resources. The study contributes to public health strategies by demonstrating brass's role in sustainable and economically advantageous solutions.

Introduction

In today's rapidly evolving world, marked by significant technological advancements and pressing societal demands, the quest for sustainable and cost-effective solutions to global challenges is more pressing than ever. Amid these challenges, the concept of "frugal innovation" has emerged as a pivotal approach, particularly valued in resource-limited settings (Hindocha et al., 2021; Rao, 2013; Zeschky et al., 2011). Frugal innovation, which focuses on maximizing resource efficiency while minimizing costs, is crucial for addressing public health challenges, especially in contexts facing rising healthcare costs and an increased prevalence of infectious diseases (Anderson & Lillis, 2010; Bhatti et al., 2017; Tiwari & Herstatt, 2012). Recent literature highlights the importance of such innovations in efficiently managing public health threats (Levänen et al., 2022; Miesler et al., 2020; Sarkar, 2021; Sarkar & Mateus, 2022). Specifically, brass, known for its cost-effective antimicrobial properties, offers a practical solution to enhance sanitation in public spaces - areas vulnerable to the rapid spread of infections (Borkow & Gabbay, 2005; Grass et al., 2011). This study explores the strategic use of brass as a frugal innovation to improve public health safety efficiently and sustainably, aiming to fill a critical gap identified in existing research (Prahalad & Hart, 2010).

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By leveraging the long-recognized antimicrobial properties of brass, this research proposes economically viable solutions to improve sanitization in high-traffic areas such as hospitals and public transport systems (Grass et al., 2011). Integrating insights from Prahalad & Hart (2010), this study extends the dialogue on frugal innovation, illustrating how brass not only meets but enhances the principles of resource efficiency, affordability, accessibility, and sustainability.

As global concerns about infectious diseases escalate, the relevance of frugal innovation principles in public health becomes increasingly significant (Bhatti et al., 2017). This research delves into the potential of brass to revolutionize hygiene practices, potentially setting new standards in public health measures in critical settings. This investigation is guided by two pivotal research questions:
RQ1: Which form of brass application is the most economically viable and effective for killing microbes on high-touch surfaces?
RQ2: Which specific applications of brass-based technology should be prioritized for maximum cost-effectiveness and microbicidal efficacy?
These questions seek to identify brass application methods that deliver maximum value with minimal resources and to strategically implement brass-based technology in real-world scenarios to maximize public health impact. The outcomes of this study promise to reshape future sanitization practices, making them more efficient, accessible, and sustainable. Moreover, the insights from this research will equip decision-makers across various sectors with the knowledge to deploy brass-based frugal technology effectively. This study stands at the intersection of material science, public health, and innovation studies, offering valuable insights poised to influence future sanitization practices and policies. Additionally, the multifaceted applications of brass, including in textiles, underscore its role as a powerful tool for microbial control and infection prevention, ensuring a safer and more sustainable future for all.

Exploring and prioritizing brass applications for enhanced sanitization

To address Research Question 1 (RQ1), this study conducted an exploratory review that identified various brass applications currently in use or under investigation. According to the Antimicrobial Copper Alloys Group (2010), brass coatings, decals, and sprays are among the solutions being evaluated for their effectiveness in public health settings. Each application form was analyzed for its cost-effectiveness and microbicidal efficacy, as well as its durability and capability to withstand the wear and tear commonly seen in high-traffic environments (Grass et al., 2011). This analysis is crucial for ensuring long-term effectiveness and sustainability in public spaces. This revealed that different forms of brass application vary significantly in their ability to kill microbes on high-touch surfaces. Studies have shown that brass coatings, in particular, provide rapid and effective microbicidal action, which is essential for public safety (Militky et al., 2021). This finding supports the selection of specific brass applications that maximize both economic and health benefits.

To address Research Question 1 (RQ1), this exploratory review identified various brass applications currently in use or under investigation (Antimicrobial Copper Alloys Group, 2010). The authors analyzed existing research to determine the advantages and disadvantages of each form, focusing on their cost-effectiveness and microbicidal efficacy. Additionally, the durability of each application form are accessed and its capability to withstand wear and tear in high-traffic environments, crucial for maintaining long-term effectiveness in public spaces. The effectiveness of different brass application forms in killing microbes on high-touch surfaces was evaluated through the literature. This approach helped to identify which forms provide the most rapid and effective microbicidal action for ensuring public safety.

Addressing Research Question 2 (RQ2), the analysis considered the cost-effectiveness and microbicidal efficacy of these applications to identify specific areas such as doorknobs, handrails, or seating that offer the highest return on investment in terms of public health and safety. This prioritization is based on a thorough review of existing data and industry best practices.

The investigation into brass application forms has unearthed valuable insights, providing a nuanced perspective on the potential of brass-based technology to enhance sanitization practices. Significant differences in the applications and properties of red brass and yellow brass were discovered. Red brass, known for its durability and corrosion resistance, and yellow brass, favored for its malleability and aesthetic appeal, both offer unique benefits for different settings (Roche Industry, 2021). The higher copper concentration in

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red brass enhances its antimicrobial effectiveness, making it particularly valuable in healthcare settings where reducing microbial contamination is crucial (Abraham et al., 2021).

Moreover, the application of copper in textiles presents a powerful tool for microbial control. Copper-infused textiles have broad-spectrum antimicrobial properties that effectively combat various microorganisms, including antibiotic-resistant strains like Methicillin-Resistant Staphylococcus aureus (MRSA) and Vancomycin-Resistant Enterococci (VRE) (Borkow & Gabbay, 2005). These textiles not only reduce the risk of skin and wound infections but also benefit individuals with allergies or diabetes, offering a comprehensive approach to infection prevention and control in healthcare settings (Borkow and Gabbay, 2004).

In addressing RQ2, the analysis highlights the importance of prioritizing brass applications in public spaces. By strategically deploying brass-based technology in hospitals and public transportation systems, decision-makers can significantly reduce microbial burdens and the risk of disease transmission. The prioritization of high-touch surfaces ensures that brass applications are used where they are most needed, maximizing public health benefits and safety.

Assessing risks and navigating challenges in brass implementation

Despite the considerable benefits brass applications offer in bolstering public health, several risks and challenges necessitate comprehensive examination and strategic mitigation. Foremost among these concerns is the potential emergence of microbial resistance over time as a consequence of sustained exposure to brass surfaces (Michels et al., 2008; Murray et al., 2022). To address this risk effectively, continuous surveillance of microbial populations and resistance patterns is imperative to gauge the efficacy and sustainability of brass-based interventions (Grass et al., 2011; Infectious Diseases Society of America (IDSA), 2011). Additionally, stringent protocols for surface cleaning and disinfection may be warranted to prevent the proliferation of resistant strains. Environmental implications represent another critical consideration in the deployment of brass technologies, particularly concerning the disposal and potential accumulation of brass materials in ecosystems (Michels et al., 2008; Sterling Group, 2018). Conducting thorough lifecycle assessments and implementing sustainable disposal practices are essential to minimize the environmental footprint of brass interventions (Johansson et al., 2020). Exploring alternative materials or surface treatments with lower environmental impacts could provide viable solutions to mitigate these concerns while maintaining efficacy. Financial barriers, particularly in economically disadvantaged settings, significantly hinder the widespread adoption of brass technologies. Addressing this challenge necessitates innovative financing mechanisms and partnerships with governmental and non-governmental organizations to offset initial investment burdens and facilitate broader implementation (Cioffi & Rai, 2012). The durability and maintenance requirements of brass surfaces also demand attention. Variations in application methods and environmental conditions can influence the longevity and effectiveness of brass interventions, necessitating tailored maintenance protocols to ensure sustained antimicrobial efficacy and operational efficiency (Mehtar et al., 2008). Equitable distribution and access to brass-based interventions are fundamental considerations to prevent exacerbating health inequalities. Proactive measures to address disparities in healthcare infrastructure and resource allocation are imperative to ensure that vulnerable populations benefit equitably from brass technologies (Spellberg & Gilbert, 2014). Lastly, successful integration of brass into existing public health infrastructure requires collaboration and coordination among diverse stakeholders. Establishing clear communication channels, standardizing implementation protocols, and addressing regulatory requirements are essential for seamless deployment and sustained effectiveness (Weber et al., 2010).

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Frugal innovation and brass-based sanitization

Frugal innovation, a strategy increasingly recognized for its potential to address complex challenges with minimal resources, emphasizes creating solutions that are simple, affordable, accessible, and sustainable. This approach aligns with the pressing need to develop sanitation solutions that are not only effective but also economically and environmentally viable, especially in high-traffic public areas (Hindocha et al., 2021). These principles are particularly relevant given the global context of resource scarcity, heightened market demand for sanitation, rapid technological advancements, and significant societal needs (Basu et al., 2013; Soni & T. Krishnan, 2014).

The core objective of this research is to identify the most straightforward and effective applications of brass for enhancing sanitization. By investigating various forms of brass applications, the study aims to determine which methods can be seamlessly integrated into existing public health infrastructures without causing significant disruptions or necessitating extensive maintenance routines (Antimicrobial Copper Alloys Group, 2010). This focus on simplicity ensures that the proposed solutions are not only user-friendly but also conducive to rapid deployment in diverse settings. This exploration is critical as it aligns with the frugal innovation's emphasis on simplicity, which not only facilitates ease of use but also promotes rapid adoption in varied public health contexts (Dabić et al., 2022; Khan & Melkas, 2020).

Affordability remains a cornerstone of frugal innovation.

The study compares the costs associated with various brass application forms, highlighting those that provide the best value for money. This emphasis on cost-effectiveness is crucial, particularly in sectors like healthcare and transportation where budget constraints are common (Bhatti et al., 2017). By demonstrating the economic benefits of brass applications, this research supports broader adoption and implementation across financially diverse settings (Abraham et al., 2021). This study highlights the cost benefits associated with various brass applications, identifying those that offer the most significant economic advantage.

Enhancing accessibility and sustainability

Accessibility is a dual concern: Ensuring that all users can benefit from improved public health measures and that these measures are easily implemented across various infrastructures. The study also assesses the durability of different brass forms, providing insights into which are most likely to endure in high-traffic environments, thus enhancing their sustainability. The antimicrobial properties of brass contribute to this sustainability, offering long-lasting effectiveness that helps prevent frequent replacements or upgrades (Borkow & Gabbay, 2005; Dauvergne & Mullié, 2021; Vincent et al., 2016). The research examines how brass applications can be made accessible across different public infrastructures and sustainable over time. Durability tests of various brass forms are evaluated to ensure long-term effectiveness, particularly in environments with high public interaction, supporting ongoing efforts to reduce environmental impact (Yu et al., 2020).

Addressing market and societal needs

The research directly responds to a clear market demand for more robust sanitization measures, a need intensified by the ongoing challenges posed by infectious diseases. Brass, with its proven antimicrobial properties, is positioned as a viable solution to enhance sanitization in public spaces, which are critical nodes in the spread of diseases. This study not only explores the efficacy of brass applications but also how these can be optimized to meet the pressing societal need for improved public health safety. By responding to the urgent demand for enhanced sanitization practices, this study positions brass as an essential tool in public health strategy, especially crucial in mitigating the spread of infectious diseases in high-traffic environments (Vardoulakis et al., 2022). It emphasizes the role of technological innovations in adapting these solutions to meet societal expectations and market demands effectively.

Extending antimicrobial applications beyond healthcare

The effectiveness of copper, and by extension brass, extends beyond healthcare environments into places such as retirement homes, kindergartens, and offices. Inkinen et al., (2017) conducted a study replacing conventional materials with copper in these settings on high-contact surfaces like door handles, light switches, and toilet flush buttons. Their findings indicated that these copper surfaces maintained significantly lower bacterial loads than those made with standard materials, proving copper's effectiveness

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across a variety of settings. Such empirical evidence supports broader implementation of brass to ensure public safety and health across different environments, leveraging its inherent antimicrobial properties.

Mapping the frugal innovation principles with brass applications

In this study, the authors have explored how the principles of frugal innovation, specifically designed to leverage minimal resources for maximum benefit, are effectively applied through the use of brass in public health initiatives. Below, the authors detail the key drivers of frugal innovation and map these directly to the characteristics and benefits of brass applications.

Resource Efficiency

Central to frugal innovation is the optimization of resource use to achieve more with less (Dabić et al., 2022). Brass, known for its durability and antimicrobial properties, exemplifies this principle. Its composition, particularly the copper content, provides prolonged antimicrobial activity, which is crucial in high-traffic public health environments. This characteristic significantly reduces the need for frequent replacements and maintenance, offering a sustainable solution that aligns with the frugal innovation's emphasis on resource efficiency.

Cost-Effectiveness

Frugal innovations aim to deliver financial sustainability by minimizing cost without compromising quality (Sarkar & Mateus, 2022). The implementation of brass as an antimicrobial surface in public health settings, while initially more costly, is offset by the reduction in healthcare-associated infections (HAIs) and subsequent savings on treatment and sanitation costs. Studies have shown that environments utilizing copper-alloy surfaces, like brass, experience a measurable decrease in infection rates, which directly translates to cost savings (Dauvergne & Mullié, 2021).

Accessibility

Ensuring that innovations are readily accessible to a broad audience is another cornerstone of frugal innovation (Albert, 2019; Tiwari & Herstatt, 2012). Brass applications in public spaces, such as hospitals and transport systems, make antimicrobial protection accessible to all users, contributing to widespread public health benefits. The ease of integrating brass into existing infrastructures replacing common touch surfaces like door handles and railings enhances its accessibility and practicality.

Sustainability

The long-term viability of an innovation is essential in frugal innovation (Albert, 2019). Brass not only offers immediate antimicrobial effects but also remains effective over time, even with repeated exposure to pathogens. This enduring effectiveness ensures that brass surfaces do not require frequent chemical cleanings or replacements, supporting environmental sustainability and ongoing public health safety (Grass et al., 2011). To visually synthesize how these principles of frugal innovation are applied through brass in public health, the following table 1 categorizes each principle alongside corresponding attributes of brass:

Table 1: Mapping the frugal innovation principles and application of Brass

Frugal Innovation Principle	Application in Brass Use	Impact on Public Health
Resource Efficiency (Dabić et al., 2022)	Durable, long-lasting antimicrobial action	Reduces need for frequent maintenance
Cost-Effectiveness (Sarkar & Mateus, 2022)	Reduces HAIs, lowers healthcare costs	Financial savings over long term
Accessibility (Albert, 2019; Tiwari & Herstatt, 2012)	Easy to integrate into existing structures	Widespread public health benefits
Sustainability (Albert, 2019)	Endures without frequent replacements	Minimizes environmental impact

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Concluding discussion and implications

This research has delved into the potential of brass applications to enhance sanitization in public health settings through the principles of frugal innovation, primarily focusing on their economic viability, sustainability, and accessibility. The investigation has confirmed that brass, provides a cost-effective solution for reducing the microbial presence on frequently touched surfaces. This aligns with findings by Borkow & Gabbay (2005) who noted the significant antimicrobial properties of copper alloys, enhancing their utility in public health applications. However, while brass offers long-term savings due to reduced disease transmission and decreased need for replacements, the initial costs can be prohibitive, particularly in under-resourced settings. The economic challenge posed by the higher initial cost of implementing brass applications highlights a significant barrier.

Despite these economic concerns, the study highlights the importance of accessibility in public health innovations. Simple and scalable solutions such as brass applications can significantly improve hygiene across diverse settings, particularly in areas lacking advanced medical infrastructure (Vincent et al., 2016). This approach not only aligns with global health priorities aimed at reducing the spread of infectious diseases but also embodies the frugal innovation mandate to create sustainable and accessible solutions (Bhatti et al., 2017).

However, the adoption of new technologies must be managed carefully to avoid potential downsides, such as increased microbial resistance or adverse impacts on existing environmental management systems (Yu et al., 2020). These considerations point to the need for a balanced approach in the implementation of brass-based technologies, ensuring that while they meet the immediate needs of public health safety, they do not inadvertently create new challenges.

The intersection of material science, public health, and innovation studies in this research highlights a multidisciplinary approach to addressing significant challenges in healthcare environments. At its core, this study leverages material science to explore the properties and applications of brass, specifically its antimicrobial effectiveness due to its copper content. Material science not only provides the technical basis for understanding how brass combats pathogens on surfaces but also guides the development of various brass applications that are tested for durability and efficacy. By examining the alloy's composition and interaction with microbial agents, material science contributes to creating solutions that are both innovative and practically applicable in high-traffic public areas. The implications of using brass are directly linked to public health outcomes. This study examines how the integration of brass in public settings such as hospitals and public transportation can reduce the spread of infections, thereby enhancing public health safety. The effectiveness of brass in lowering infection rates and potentially decreasing the incidence of healthcare-associated infections (HAIs) aligns with the goals of public health to safeguard communities and improve environmental health conditions. The research here responds to urgent public health needs by providing a preventive strategy against microbial transmission, which is a pressing concern in public health management. Innovation studies provide the framework for applying frugal innovation principles to the use of brass in public health settings. This field explores how innovative, cost-effective, and accessible solutions can be developed and implemented to meet specific needs, particularly in resource-constrained environments. The study's focus on frugal innovation through the use of brass underscores the importance of developing practical, scalable, and economically viable technologies that can be widely adopted. It addresses how innovation in material applications can be a game-changer in public health strategies, especially in enhancing the sustainability and accessibility of health interventions. The convergence of these three domains in the study leads to a comprehensive understanding of how advanced materials can be utilized to meet public health needs while adhering to the principles of innovation. By integrating material science with public health imperatives and innovative application strategies, the research not only contributes to the academic discourse but also provides actionable insights for policymakers, healthcare providers, and other stakeholders in the health sector. This multidisciplinary approach ensures that the solutions developed are not only scientifically sound and effective but also aligned with the broader objectives of public health enhancement and sustainable innovation.

While brass is extensively discussed in this paper for its antimicrobial properties and potential applications, it's essential to consider a range of alternative materials to provide a comprehensive understanding of available

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options. In addition to brass and copper, materials such as titanium dioxide (TiO_2), silver, and nanotechnology-based solutions offer unique advantages and applications in enhancing public sanitation. Titanium dioxide is a versatile compound known for its photocatalytic properties, making it effective in degrading organic pollutants and inhibiting microbial growth under UV light exposure (Armaković et al., 2022). TiO_2-based coatings have shown promise in reducing the survival and proliferation of various pathogens, including bacteria, viruses, and fungi, on surfaces such as medical equipment, countertops, and packaging materials and it continuously generate reactive oxygen species upon exposure to light, disrupting microbial cell membranes and DNA and providing long-lasting antimicrobial activity (Kumaravel et al., 2021). TiO_2 coatings are compatible with a wide range of substrates, transparent, and environmentally friendly, making them suitable for diverse applications in public health settings (Tian et al., 2023). Silver has long been recognized for its antimicrobial properties and has been widely used in healthcare settings to inhibit microbial growth on surfaces and medical devices (Lansdown, 2006). Silver-based coatings or nanoparticles have shown efficacy in reducing the survival of bacteria, viruses, and fungi, making them suitable for various applications, including wound dressings, catheters, and water purification systems (Xu et al., 2020). While silver offers effective antimicrobial protection, concerns have been raised regarding potential toxicity and environmental impact associated with its widespread use, necessitating careful consideration of these factors in decision-making (Bruna et al., 2021). Advancements in nanotechnology have led to the development of novel antimicrobial materials with enhanced efficacy and versatility. Nanoparticles, such as silver nanoparticles, zinc oxide nanoparticles, and graphene oxide, exhibit strong antimicrobial properties due to their high surface area-to-volume ratio and unique physicochemical properties and these nanoparticles can be incorporated into coatings, textiles, and medical devices to provide durable and effective antimicrobial protection (Sirelkhatim et al., 2015). However, challenges remain in scaling up production, ensuring safety, and addressing potential environmental concerns associated with nanomaterials (Ray et al., 2009). While brass remains a promising option for enhancing public sanitation, exploring alternative materials such as titanium dioxide, silver, and nanotechnology-based solutions can offer additional options for addressing microbial contamination in public spaces. Each material presents unique advantages and considerations, highlighting the importance of evaluating their suitability based on specific application requirements and environmental considerations.

Limitations and scope for future research

Despite the promising findings, this study is subject to several limitations that should be considered when interpreting the results. The study primarily draws on existing research and industry best practices, which may not be universally applicable. The economic assessments of brass applications were primarily based on theoretical models and retrospective analyses, which may not fully capture the real-world complexities of implementing such technologies in diverse settings. Furthermore, the study's focus on brass might limit the exploration of other potentially more cost-effective or sustainable materials. Additionally, the resistance development among pathogens due to continuous exposure to brass surfaces has not been fully explored, which could undermine the long-term effectiveness of these interventions. Given the identified limitations, future research should focus on several areas to expand the understanding and application of brass-based technologies in public health. Prospective studies are needed to evaluate the real-world efficacy and cost-effectiveness of brass installations in various environmental conditions and usage patterns. Such studies could help validate the findings from this research and adjust implementation strategies based on empirical data. Additionally, comparative studies involving other antimicrobial materials could offer insights into the relative performance and sustainability of different options, guiding resource allocation in public health investments. Research into the potential resistance development among pathogens in response to continuous exposure to brass surfaces is also crucial. Understanding these dynamics will inform the design of interventions that minimize the risk of creating resistant microbial populations. Lastly, interdisciplinary research combining material science, public health, and behavioral sciences could explore how the design and deployment of antimicrobial technologies influence user behavior and overall public health outcomes. Such research would provide a holistic view of how innovative materials can be effectively integrated into public health strategies to maximize their benefits and sustainability.

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