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RESEARCH ARTICLE:

Exploring the Aesthetic Applications of Expanded Polystyrene: An Interdisciplinary Review

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Abstract

Some researchers contend that repurposing and reuse of EPS for artistic and aesthetic purposes represents a meaningful step in addressing the environmental challenges associated with its widespread commercial and single-use applications. It is in line with this thought that this review paper seeks to explore the wide range of creative and aesthetic applications of polystyrene across various disciplines, shedding light on its versatility, aesthetics, and functional qualities. The purpose of the review is to ascertain the contribution of the creative field to environmental sustainability through the (re)use of EPS. Taking a qualitative route, this review of literature is guided by the following research questions: (a) What are the inherent properties and characteristics of EPS? (b) In what myriad aesthetic contexts have EPS found utility and application? (c) What are the key challenges associated with employing this material for artistic purposes? Given the difficulty that accompanies the recycling options for EPS, its use in art has become another avenue for extending the material's end-of-life use. However, the paper found that while some artists contribute to the development of a green society by using discarded EPS in their art, others contribute to the problem by choosing to use virgin EPS for their art because of benefits such as the material's lightweight, ease of carving, and cheapness. Therefore, this paper recommends that if artists must use EPS, then they should make it a point of duty to go for discarded EPS and other plastic wastes to help the environment.

Keywords: *aesthetics of polystyrene; art and sustainability; art and science; aesthetics of materials; expanded polystyrene*

Introduction

The interdisciplinary relations between engineering and the creative disciplines have been facilitated by several factors, including materiality. The development of different materials with differing properties for different purposes and applications, which has been at the core of material science, has also benefited the visual and creative fields through the development of creative and durable material options for the tangible, tactile, and visual interpretation of the diverse ideas consistently generated by the actors in this field. The focus of this paper will be on expanded polystyrene (EPS). EPS is a versatile and widely used synthetic polymer that has gained significant attention in the creative fields for its diverse applications and properties. According to Harris (2019), EPS has been used as an aesthetic medium for expressing conceptual thoughts in visual arts. From sculpture to packaging design, EPS has emerged as a material that offers intriguing creative possibilities.

Despite the versatility of its application possibilities, EPS has been associated with certain concerns regarding its recyclability and contribution to environmental waste pollution (Verma *et al*., 2016; Chaukura *et al*., 2016). In recycling EPS, there are two major approaches to de-foaming the material before it is used for other purposes: solvent-based and mechanical approaches. The solvent-based approach sometimes causes more carbon emissions if care is not taken, except if plant-based oils are used. However, plant-based oils are not cheap, hence their use is not popular. The other approach is to mechanically compress the foam to remove its gas, so that it can

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be re-gassed for other purposes. In both approaches, recycling EPS proves to be a costlier process when juxtaposed with the utilisation of virgin EPS. This financial implication is a key driver behind the continuous production of EPS materials (Gallego-Schmid *et al*., 2019; Chaudhary and Vijayakumar, 2020; Schyns and Shaver, 2021).

Nonetheless, art has been seen as one of the fields where EPS finds another life when it reaches its initial end-of-life use. Some researchers contend that the repurposing and reuse of EPS for artistic and aesthetic purposes represents a meaningful step in addressing the environmental challenges associated with its widespread commercial and single-use applications (Guy *et al*., 2015; Singh and Sharma, 2016; Kehinde *et al*., 2020). It is in line with this thought that this paper seeks to explore the wide range of creative and aesthetic applications of polystyrene across various disciplines, shedding light on its versatility, aesthetics, and functional qualities. The purpose of the review is to ascertain the contribution of the creative field to environmental sustainability through the (re)use of EPS. Taking a qualitative route, this review of literature will be guided by the following research questions: (a) What are the inherent properties and characteristics of EPS? (b) In what myriad of aesthetic contexts has EPS found utility and application? (c) What are the key challenges associated with employing this material for artistic purposes?

An Overview of Expanded Polystyrene

Polystyrene is a fossil fuel-based polymer produced from the aromatic styrene monomer. It is a liquid hydrocarbon (Connor, 2019). At room temperature, it is a sold thermoplastic. At increased temperatures, it can be extruded or moulded. Polystyrene is a polymer made from the polymerisation of styrene monomers (See Figure 1). It can be produced in an expanded form or compact form based on the type of use it will be put to (Uttaravalli *et al*., 2020).

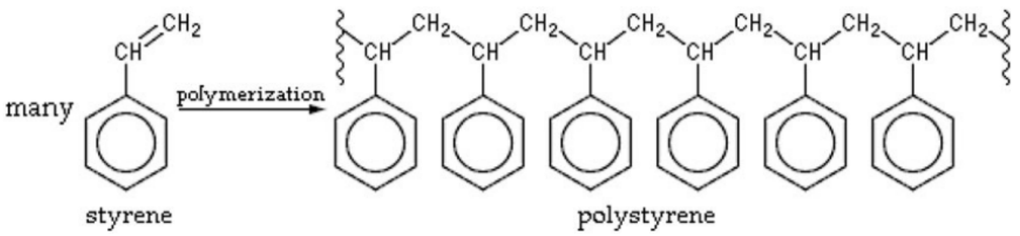

Figure 1: Structure of Styrene Monomer and Polymer (Ho *et al*., 2018)

EPS is a lightweight material, used mainly in packaging applications. The three forms of EPS have been illustrated in Figure 2. The major disadvantage linked to polystyrene is that it is not an eco-friendly material. It is not biodegradable and therefore contributes to the plastic pollution crisis. EPS is a mixture of 5% polystyrene and 95% air (Ho *et al*., 2018). EPS is a type of plastic material containing small hollow spherical balls fused together. It is rigid and tough. EPS possesses poor water and vapour permeability (Connor, 2019).

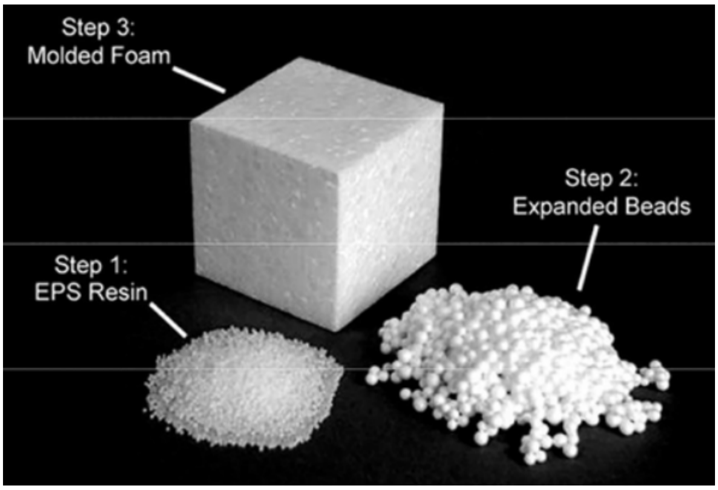

Figure 2: Three forms of expanded polystyrene (Ramli Sulong *et al*., 2019)

EPS finds applications in several sectors including construction, and packaging. Due to the highly combustible nature of expanded polystyrene, it is used in conjunction with other fire retardants for construction purposes (Koksal *et al*., 2020). EPS exists in several forms. The three most important forms are resin form, expanded resin form, and moulded foam (Ramli Sulong *et al*., 2019). EPS is commonly used in the production of disposable cups, trays, and plates. This is partly because it is relatively less expensive compared with its polyethylene and polypropylene counterparts. These cups and trays are usually used only once, after which they are disposed of. Therefore, they fall under the single-use plastic category. As a result of its porous and lightweight structure, EPS is a costly material to recycle (Coelho, 2022). The primary properties of polystyrene depend largely on the density. Understanding the physical and chemical properties of a polymeric material is necessary to envisage the performance of the polymer under various conditions and applications. Table 1 provides the physical and chemical properties of EPS.

Table 1: A summary of the physical and chemical properties of EPS beads

Properties	Details/values
Polymer	Polystyrene $(C_6H_6CH_2CH_2)n$
Content of polystyrene	95-100%
Molecular weight	>40,000
Colour	White or coloured
Physical state c	Cellular foam and granulated particle
Odour	Slightly hydrocarbon odour
Blowing agent content (pentane)	>6% or <1%
Bulk density	610kg/m^3
Nominal density	8.5-60kg/ m^3
Minimum compressive stress at 10% deformation	50-165kPa
Minimum cross-breaking strength	95-320kPa
Softening temperature	50-165 °C
Melting temperature	170-200°C
Ignition temperature in air	350-427°C
Minimum aging time of pre-expanded beads	8h
Maximum rate of water vapour transmission	400-710$\mathcal{M}$g/m^2s
Volatile content	< 1%
Solubility in water	Not soluble
Solubility in other solvents	Soluble in aromatic, halogenated solvents and ketones

Source: Prasittisopin *et al*. (2022**)**

Methodology

The research questions for this study were generated based on a preliminary search of different databases including Google Scholar and Wiley. Given the limited availability of publications that explore the interdisciplinary intersections of the arts and material sciences, particularly in the context of polystyrene, Google Scholar was selected as the primary database for sourcing relevant literature. This choice was made because alternative databases such as Wiley, ProQuest Central, and Web of Science yielded only a sparse amount of results. Based on the research questions, pertinent literature in the area of creative and aesthetic use of EPS was gathered using the following key phrases: Properties of Expanded Polystyrene; Expanded Polystyrene Sculpture; Polystyrene and Installation Art; Polystyrene and Packaging Aesthetics; Expanded Polystyrene and Set Design in Theatre; Expanded Polystyrene and Architectural Interior Design; Expanded Polystyrene, Environmental Impact and Sustainability. For each key phrase used, relevant literature was retrieved from Google Scholar to the 100th page. This process resulted in the selection of 398 literature.

The abstracts of all selected articles were carefully read and reviewed to ascertain their relevance to the research questions of the review and assess their suitability. Additionally, duplicates were also identified and eliminated in this process. The inclusion criteria for the study encompass peer-reviewed academic journal articles, book chapters, conference papers, postgraduate theses, exhibition reviews, and case studies of projects published within the last decade (2013 to 2023) that demonstrate interdisciplinary research. Conversely, the exclusion criteria pertain to articles not in English, grey literature, publications older than ten years, papers concentrated on the use of expanded polystyrene for structural or thermal applications, and articles lacking evidence of a rigorous peer-review process, specifically those not published in recognized journals. After applying the inclusion and exclusion criteria, the number of selected articles was reduced to 115.

To enhance the scope of this review, the authors have slightly extended their focus beyond the extracted data from the primary database. In addition to the gathered information, the review encompasses case studies of sculptors who have extensively utilized polystyrene in their work, yet have not received adequate coverage in peer-reviewed literature. These case studies are integrated into the analysis and discussion of the collected data, shedding light on how contemporary sculptors have harnessed the distinctive attributes of polystyrene to craft visually captivating and conceptually thought-provoking artworks, in line with the research questions of the review.

Aesthetic Applications of Expanded Polystyrene

Beyond the intuitive generation of ideas, one major ingredient for the contemplation and appreciation of the aesthetics of creative ideas is their physical materiality. It is in a similar line of thought that Ashby and Johnson (2013) submit that the aesthetics and physical properties of a product are ultimately determined by the materials and processes with, and through which, the product was created. Within the context of this paper, the aesthetic formality of creative ideas, as structured by different creators' use of EPS, is being considered. In Rhodes's (2018) trace of the pivotal developmental trajectories in the field of plastic production, it was noted that polystyrene was first produced in the 1930s by IG Farben while its foam expanded form was subsequently developed by the Koppers Company in Pittsburgh, Pennsylvania, under the trade name 'Dylite' in 1954. Conversely, however, both McClung (2016) and Baker (2018) claim that the commonly known foam called expanded polystyrene was created and trademarked 'styrofoam' in the 1930s by the Dow Chemical Company.

This was created during an experiment by adding isobutylene to a form of styrol, which is the main ingredient in polystyrene (McClung, 2016). This is contrary to Rhode's account which points to 1954 as the year EPS was developed. Despite these contestations, one thing that is clear is that the historical footprint of polystyrene emerged in the 1930s during the Great Depression. This period was a time of devastating economic downturn, which affected global production and consumer behaviour. It is therefore not surprising that the manufacture of polystyrene, a material known for its cheapness and ease of production, coincided with this period. In addition to its cheapness, the ease of manipulation – carving in this context, has made EPS a material of choice for artists and designers. Morgana (2023) notes that EPS is chosen by artists for different reasons such as its white aesthetic appearance which is why they often leave the material in its natural colour; its lightweight and visual mass; water resistance; and to conceptually address environmental issues such as plastic pollution. Thus, the use of EPS in different aesthetic applications has its origin as far back as the early 1950s (Clarke, 2013). The subsequent part of this section will therefore review, with relevant examples, the different creative subfields in which EPS is being used.

EPS in sculpture and installation art

The use of EPS in sculpture has grown in recent decades among artists. For reasons such as the whiteness of the material, the ease of carving and the possibility of creating gigantic but lightweight sculptures, EPS has gradually attained the status of an 'exotic material' amongst contemporary sculptors globally. For instance, Jones (2019) adopted EPS as a major material in his practice-led doctoral research because he found it an easy and quick material to carve. In his words "Increasingly, polystyrene…has come to be regarded as a virtual 'demonic substance'; a violation of nature and a defining feature of our 'anthropocentric era'" (Jones, 2019:101). The adoption of this 'exotic' and 'demonic' material by Geoffrey Clarke, a sculptor who experiments with different materials including EPS, earned him the description as a "space-age sculptor" in an exhibition catalogue (Clarke, 2013). The sculptures and installations crafted from EPS can generally be categorized into two primary groups. The first category comprises works primarily fashioned from virgin EPS due to the material's distinct properties, while the second category consists of pieces predominantly created from discarded and recycled EPS. The latter category often serves as a conceptual response to environmental pollution and degradation concerns. In this discussion, we will begin by examining the first category.

For many contemporary sculptors, EPS is a material of choice because it provides great surface detail and it is also lightweight which is an important consideration for installation. This fact is clearly evidenced in the fabrication of the physical replica of Nicola's semi-abstract bas-relief sand-cast, where EPS panels manufactured using a robotic technology called 'the KUKA KR210 R2700 6-axis robot were used (Ahsan et al. 2022). The ease of carving which is a unique property of EPS, is another reason its use is prevalent amongst artists. Thus, Lin May Saeed, a German-Iraqi sculptor carves EPS by hand in a playfully free manner. Lin creates a lot of works in EPS, mixing it with other materials and sometimes painting it. The artist also explored the natural white aesthetic of the material while she also converted the form created with the material into solid casts of bronze. In a bid to restore the lost relationship between animals and humanity, Lin created multiple-figured installations consisting of forms of animals, humans, and other natural elements, using EPS (Herman, 2023). Like Lin, Chinese artist, Cia Guo Qiang also sculpts animals using EPS. Over a six-year period, the artist in collaboration with the Queensland Art Gallery created a large collection of animals with EPS. In a departure from Lin's EPS animal forms, Cia aimed for a more realistic presentation of her works. Thus, the animals created by Cia were covered with dyed goatskin (Wild, Pagliarino and Storer, 2016; Łakomska, 2021). The whiteness of EPS also drew Gennari (2017) to the material. Capturing the expedition in the Arctic region, Gennari used hotwire to carve EPS foam blocks into different ice forms. The whiteness of the EPS material gave an apt representation of the visual properties of icebergs.

In a collaboration between MA Art students and PhD. physics students in communicating scientific concepts through art. EPS shaped into balls/spheres were used in an interactive installation during the exhibition to illustrate a continuous model of molecular behaviour. The light weight of the material made it the best option for the installation aim (Walker and Von Ompteda, 2014). In the case of Kordik (2015), the material was chosen for its textural quality, largeness, cheapness and availability. Kordik's leaf exploration and installations during his Master's research entailed carving and melting EPS into leaf forms. He then painted on the leaf forms using acrylic. Sometimes, EPS beads are used in installations for their fluffy light quality. In an installation titled Walking in Venus Blue Cave (2001) by Ernesto Neto, the fluffy bed that runs through the floor of the installation space was made using EPS beads (Moomaw, 2016). Beaded EPS such as the foregoing are either created using virgin or recycled EPS. Sometimes, for outdoor installations, carved EPS forms are coated with other materials for durability. This is exemplified in an installation that explores the complex interconnectivity of nature through play (Ji and Wakefield, 2018). After hand sculpting, wire cutting, and sanding some of the EPS forms in the installation, it was coated with aqua-resin for durability and added aesthetics. Similarly, glass-fibre reinforced concrete (GFRC) was used to coat a megalith, which was the central focus of Clifford's (2016) study which sought to dis(prove) the validity of a historical myth that megaliths walked themselves as opposed to the more logical assumption of being carried. The megalith was created using a solid core of EPS. The coating of the EPS core was done for weight, solidity, and surface durability. In the case of Sugar Baby, a 75-foot-tall female sphinx hand-carved from an EPS core, a white sugar solution was applied as an external coat for added surface solidity and durability (Larson, 2014). It is important to point out here that for sculptors who have ambitions of creating large-scale sculptures with the cheapest and easiest material to use in terms of manipulation, EPS is usually used. This is one of the reasons why the African-American artist Kara Walker, who created Sugar Baby, chose EPS. EPS was used for its ease of carving, which makes it easy to archive such enormity in size, as well as for the material's whiteness which aligns with the visual whiteness of sugar (Brophy, 2019).

For a similar reason, Nigerian contemporary sculptor, Bale Ola-olu Olawale also creates his large-scale outdoor sculptures using virgin EPS (Fifth Chukker, 2017). Since most of his works are outdoor sculptures, the sculptor often coats his creations with a thick layer of reinforced fibreglass for increased protection from weathering, durability and longevity (See Figure 3). Davies (2015) acknowledges that EPS can also be used for some dimensions of miniature art like creating landscapes and small hills, provided that it is coated with poly-vinyl-alcohol (PVA). However, Davies warns that it is safer to use other kinds of foam such as XPS and stay away from EPS altogether because it has proven to be too delicate for the handling required in wargaming. However, one should note that the suitability of materials for different creative and aesthetic purposes is not universal, but dependent on several factors such as the preference, skill and experience of the artist or designer, as well as the availability of such materials.

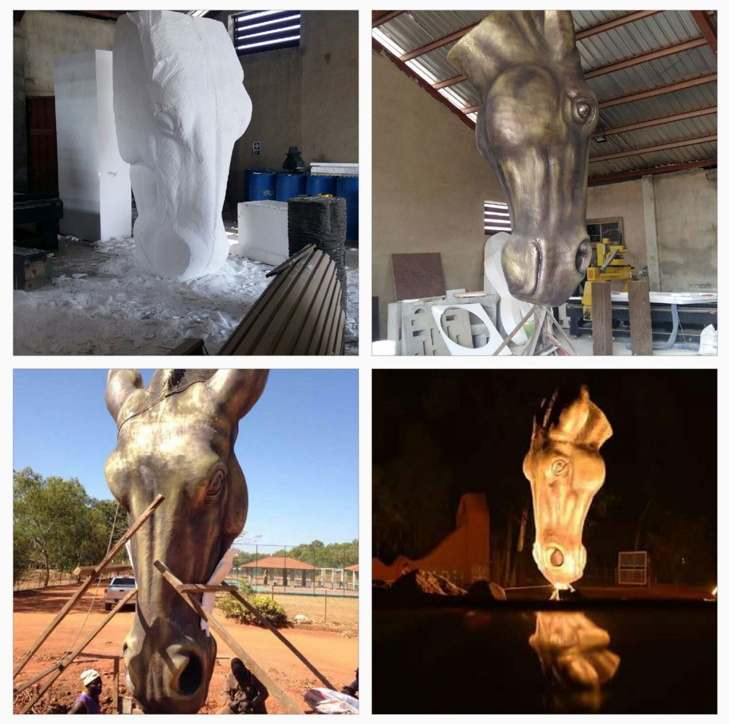

Figure 3: The Horse Head, Bale Ola-olu Olawale, Reinforced Polystyrene, 4.2 Meters,
Source: Fifth Chukker Resort Kaduna Nigeria, Courtesy of the Artist.

As the conscience of society, it falls within the purview of the artist's social and environmental responsibility to advocate for a safe, green and sustainable environment through their art. This summarises the conceptual basis for the second category of works created using EPS. Li (2020) considers the EPS waste stream as an inspirational source rather than a source of pollution and environmental Hazard. During a six-week residency, Li engaged with a range of modern waste materials at a construction, demolition and waste recycling centre Revolution Recovery, Philadelphia. The engagement resulted in an experimental interrogation and an aesthetic display of the magnitude of the waste left behind in modern consumer culture. Waste EPS, moulded and compacted into huge blocks in varied patterns were the result of this process. Li then exhibited the installation blocks in a gallery to give people an opportunity to appreciate the magnitude of the problem being caused by waste plastics to the environment. In a similar iteration, with an aim to combat the problem of plastic waste in the environment for ecological sustainability, German-born sculptor Wolfgang Weileder, designed and constructed "Stilt House" from a combination of waste plastics, including EPS. Guy *et al*. (2015) are of the opinion that this kind of art intervenes in and represents the issues of climate change and environmental sustainability. This fundamentally foregrounds the role of the arts and artists in the fight against plastic pollution towards environmental sustainability.

In the exhibition titled "The Age of Plastics", according to Hume (2013), the artist takes a conceptual look at the global problem of plastic including EPS. To explore the unusual relationship between plastic waste and ceramics, the artist used different forms and types of plastic waste as moulds to conceptually create different ceramic forms through the slip-cast method. For Tse, mass-produced industrial materials such as EPS reflect human society's cultural, economic and political orientation and progressions. She creates elaborate installations using EPS (Chung, 2021). With his EPS installations, Jason Rogenes an American sculptor explores ideas of pop culture and consumerism. He transforms the discarded and simplistic material into spectacular futuristic structural forms, complete with lights (Leonard, 2022). Jason believes that there is no need to paint the EPS as it breathes and accentuates its own unique form (Morgana, 2023). As a result, although Jason works with discarded EPS, he leaves the material in its original white form which is further accentuated and illuminated by light fixtures within the installations. Sharing a conceptual and visual affinity with Jason's sculptures, Bolbolabadi (2022) also transforms waste packaging materials into interesting pieces with an aim to reduce industrial waste. Thus, Bolbolabadi recycles electronic packaging EPS to create mixed-media sculptures.

The use of EPS in sculpture is not limited to the form of the work alone. EPS is also used in some casting processes for sculpture. Clarke uses EPS in his metal (bronze, aluminium,) casting process where he melts the EPS with the heat of the molten metal, instantly replacing the EPS form with the metal (Clarke, 2013). Called the full-mould technique, it was developed at the Massachusetts Institute of Technology by a Sculptor – Alfred M. Duca, in the late 1950s. Duca developed an innovative technique called the 'Foam Vaporization' method as an evolution of the ancient lost wax process. In this method, a sculpture crafted from polystyrene is enclosed within a sand mould. Molten metal is then poured into the mould, causing the foam to vaporize and leaving behind a distinctive, solid casting. After thorough refinement, including experimentation with various venting methods, MIT employed this technique to create more than 30 works of art, including Duca's bronze Pegasus in 1959 (Belasco, 2014). This technique is however restricted to hot metal casting.

For casting in other materials such as fibreglass, other casting methods such as plaster casting, silicon casting, glass-fibre reinforced concrete cast and slip cast for ceramics (Fernández *et al*., 2015; Garcia-Garcia, Chulvi and Julia, 2017). In all of this process, EPS is often used to first create the desired form before being transformed into a more durable material through the casting process.

EPS and its aesthetic relationship with architecture and engineering

EPS has also been used to combat the problem of housing, as it provides a relatively cheap alternative to conventional housing methods (Mncwango, 2019). EPS is currently being used for aesthetic purposes in construction in areas like North America, instead of other stone materials. Beyond the construction of affordable housing, EPS cornices and decorative mouldings and tiles are installed on walls to improve the overall aesthetics and conceal gaps and inconsistencies in wall surfaces (Ramli Sulong *et al*., 2019; Pärkson-Kull, 2015). Just as in the case of sculptors, the ease of carving and manipulation as well as affordability makes EPS a material of choice for architects and designers. In the creation of Natividade's (2018) formwork for a façade construction, EPS was the material of choice for its affordability, lightweight, milling speed, and accuracy. EPS also proved capable of resisting the force that accompanies the casting process. In congruence, because of the weight and intricacies that capitals usually possess, it is often daunting to use clay in such carvings. Thus, according to Tuttle (2013), EPS was used to hand-carve the capital during the 'faux' restoration process. Neat (2013) also identifies EPS as one of the materials used in making models. For its cheapness and availability, it is often used in building up landscapes in model making. Neat however claims that it is not best for forms requiring details. Also, some worries have been expressed about the use of EPS in buildings considering its flammability (Ramli Sulong *et al*., 2019). This was however improved, as noted in Ramli Sulong *et al*. (2019), by the addition of diammonium phosphate flame retardant to a wood composite made of wood flour and EPS waste. This improved the composite's fire-resistant properties, making it safer to be used in architectural applications.

EPS is often used in creating architectural and engineering prototypes because of its alignment with robotic design tools such as Computer Numerically Controlled machines (CNC). The introduction and use of robotic machines, such as CNC, have made the sculpting of EPS easier for aesthetic and commercial purposes (Ahsan *et al*., 2022; Clifford, 2016). Most designers who use CNC machines prefer to use EPS to achieve complex design possibilities. The need for precision in the fabrication of the formwork for façade systems necessitated the adoption of EPS, carved by CNC (Ponitz and Cabrinha, 2016; Starrett *et al*., 2018; Natividade, 2018). For instance, Weir et al. (2018) used EPS in the construction of an architectural prototype using the robotic hotwire cutting technique. Similarly, in achieving the initial form of the robot, EPS was carved using an industrial robotic carving machine (CNC). The EPS form was thereafter taken through the casting process and the final material of the robot becomes fibreglass resin (Fernández *et al*., 2015). In exploring innovative approaches to ceramic production, the authors adopted the CNC technology to create EPS formers with which slip-casts were then created. To achieve unusual shapes in ceramics, outside the throwing technology, EPS was carved with CNC to create moulds and formers for slip-casts (Wanner and Urbano Gutierrez, 2016). In this manner surfboards are also industrially produced using CNC technology (Gibson and Warren, 2017).

EPS in theatre and puppetry

A few literatures encountered in this review points to the fact that different types of foams are used in the design and construction of props and sets for theatre and puppetry, including EPS (Currell, 2014; Raj *et al*., 2018). In Rightmire (2014), Boulders of EPS were hand-carved for a theatrical setup to create an illusion of weight. After carving, the boulders were painted. Ying and Chiat (2014) also allude to creating rocks for theatre design from EPS. In an experimental and conceptual use of EPS, the Pink Floyd Revolution group built a huge wall with EPS bricks which is a main component in the concept and execution of their act. At some point, the wall divides the performers and their audience (Crippa, 2020). In Ghana, wood has been the premier material for stage/theatrical designs. Nonetheless, Adjahoe (2022) alludes to the use of EPS and other waste materials by some designers in some instances. Cole (2022) adds that EPS was also used in the development of a prototype for a scenic stage design in alignment with the requirements of The Insect Play by Karel Čapek. According to Asllian (2016: 104), "Kheymeh Shab Bazi is a traditional Iranian marionette puppet theatre that changed during and after the Qajar dynasty in various aspects." After the Islamic revolution, EPS emerged as a material with which the heads of Kheymeh Shab Bazi puppets were created.

EPS in product design and packaging aesthetics

The aim of creating aesthetic product design and packaging is to attract, persuade, and convince customers to purchase the product. Thus, the formal aesthetics of a product's appearance is a result of the materials it was composed of, and the techniques employed to form, connect, and refine those materials (Ashby and Johnson, 2013). Since its invention and proliferation commercially, EPS has been used in the design and packaging of different products. For instance, EPS is one of the preferred materials for making surfboards. This is because it lasts longer than polyurethane and performs better than wooden boards. Such surfboards are either handmade or industrially produced using CNC technology. Recycled EPS is sometimes used to make surfboards. Although this is seen as a way to reduce the carbon footprint associated with using a virgin EPS for production, the recycling process still requires energy to blow the EPS into a surfboard blank, hence generating carbon emissions and impacting the environment (Gibson and Warren, 2017).

Focusing on contemporary furniture design and materiality, Max Lamb's White Poly Chair from 2010 was hand-carved from a block of EPS (Ratcliff, 2018). Dahmen, Soules and Frid-Jimenez (2013) also explored the use of waste in creating soft seating structures. In their exploration, they used discarded EPS, which was shredded and stuffed into discarded Teflon-coated fibreglass fabric. The major output from the project is pop rock, soft seating structures for outdoor spaces. This demonstrates different approaches employed by designers in their contribution to waste management and the use of EPS in contemporary landscape designs and furniture constructions. Also, as part of the efforts to combat the problems of EPS waste, Abdullah and Lamat (2015) and Abdullah and Osman (2019) created a composite material from recycled EPS containers for the fabrication of bicycle frames. It is therefore safe to conclude that like sculptors, product designers can also be grouped into two categories in their use of EPS – those who use virgin EPS for the sake of its properties, and those who use recycled EPS to create their designs to aid the fight against environmental plastic pollution.

Challenges and Considerations

The global plastic pollution problem is reaching alarming levels, driven by the staggering scale of plastic production and its persistent nature. Annually, the world produces over 300 million metric tons of plastics, with nearly half of this volume dedicated to disposable applications, products discarded within just a year of purchase (Singh and Sharma, 2016). Plastics, being cheap to produce and non-biodegradable, have led to an accumulation of billions of tons in the environment, resulting in a severe ecological crisis (Rhodes, 2018).

In recent years, according to Alabi *et al*. (2019), plastic production has surged, reaching an estimated 380 million tonnes globally in 2018. Since 1950, an astonishing 6.3 billion tonnes of plastics have been produced worldwide, with only a meagre 9% recycled and 12% incinerated. A significant portion of this plastic, approximately 5 million tonnes yearly, is consumed in the UK alone, with a mere one-quarter being recycled, and the remainder ending up in landfills. This rampant plastic consumption is taking a devastating toll on our oceans, with predictions suggesting that by 2050, the weight of plastics in the oceans may surpass that of fish. Each year, around 500 billion plastic bags are used, contributing to an estimated 13 million tonnes of plastic pollution in the oceans, resulting in the tragic death of approximately 100,000 marine creatures. Furthermore, plastics constitute about 90% of marine litter, with trillions of plastic particles floating on the ocean's surface (Lacerda *et al*., 2019). This environmental catastrophe is not limited to the oceans; it also affects human health as microplastics, ingested by a wide range of aquatic life, bioaccumulate in the food chain, posing a significant public health risk. Studies reveal that plastics persist in human populations through environmental contaminants, highlighting the urgent need to address this global plastic pollution crisis (Lacerda *et al*., 2019).

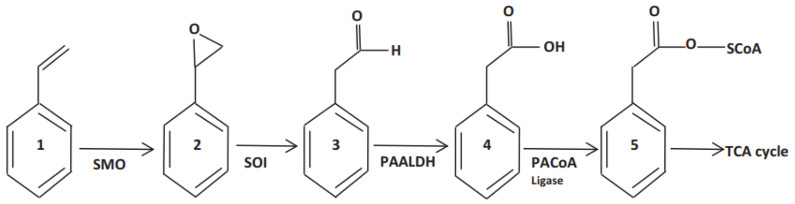

Figure 4: Degradation pathway of polystyrene. 1- styrene, 2-Styrene Oxide, 3- Phenyl acetaldehyde, 4- Phenyl acetic acid, 5- Phenylacetyl coenzyme A.
SMO: Styrene Monooxygenase; SOI: Styrene Oxide Isomerase, PAALDH: Phenylacetaldehyde Dehydrogenase, PACoA ligase: Phenylacetyl Coenzyme A ligase (Ho *et al*., 2018).

Figure 4 presents the non-degradability or highly slow and stable degradation pathway of polystyrene. The non-degradability of EPS is a major contributor to global plastic pollution with significant environmental and health implications (Lacerda *et al*., 2019). A shocking 2.3 billion pieces of plastic were recovered from a Southern California beach in just 72 hours, weighing approximately 30,500kg. The majority of this debris consists of foams like polystyrene, comprising 71% of the total, further exacerbating the issue of marine litter (Verma *et al*., 2016). EPS waste, like other plastics, is lightweight and easily carried by the wind, eventually finding its way into water bodies, where it can have detrimental effects on marine life (Babayemi *et al*., 2019). These particles can cause entanglement and ingestion by marine animals, leading to suffocation and death (Hahladakis *et al*., 2018). The problem of EPS extends beyond its presence in the environment. Polystyrene is known to be harmful to the central nervous system, and when burned, it releases toxic chemicals that pose a severe health risk to humans. These risks include heart diseases, aggravation of respiratory ailments like asthma, skin issues, and damage to vital organs like the kidneys and liver. Additionally, dioxins from burning EPS can contaminate crops and waterways, entering the food chain (Verma *et al*., 2016). While EPS is commonly used by artists, its environmental impact is problematic. The excess or discarded EPS created during artistic processes contributes to the EPS waste problem. Recognising these environmental and health hazards, some regions in the US, including Washington DC and New York, have implemented bans and restrictions on EPS, particularly for food packaging (Blackwood, 2016). Therefore, it is essential to recognise the urgent need to manage EPS waste effectively and reduce its usage to mitigate its detrimental effect on both the environment and public health. This is even more crucial amongst developing populations in the world such as Africa, where waste management systems are significantly poorer (Babayemi *et al*., 2019).

EPS poses a significant environmental challenge due to its slow biodegradation rate in natural environments, leading to long-lasting solid waste. However, two strategies have shown promise in addressing this issue. The use of pure microbial strains and complex microbial communities has demonstrated that EPS can be biodegraded, albeit at a slow rate (Ho *et al*., 2018). While some studies have reported minimal degradation even after several decades, as highlighted in Ho *et al*. (2018), there is evidence that microbial activity can contribute to EPS breakdown over time. This suggests that harnessing the potential of microbial degradation could offer a solution to the persistence of EPS in the environment. Artists, and designers in particular, have embraced the concept of reusing EPS to create innovative and sustainable artworks. Nick Hornby, a London-based British artist, introduced a unique approach to utilising EPS in sculptures, installations, and packaging. In preparation for an upcoming exhibition, Hornby crafted a series of 30 semi-abstract busts, all derived from a single block of EPS. His intent was to showcase these busts during the exhibition, and once the show concluded, they would undergo a transformation, being shredded to serve as packaging material for other artworks destined for return (Schrock, 2014). This unconventional practice introduced a captivating facet to the inherently ephemeral nature of certain art forms. It also introduced a paradoxical element: although EPS is renowned for its notorious non-biodegradability, its role in the art world could be characterised as temporary, fleeting, and ultimately ‘degraded’.

Two of the methods Rhodes (2018) suggested for the reduction of plastic waste are recycling, and non-usage or reduction in the usage of plastic materials. In regions with advanced waste management systems, including recycling, reuse, landfill, and incineration, recycling is regarded as one of the most effective methods for dealing with plastic waste (Singh and Sharma, 2016; Thakur *et al*., 2018). Recycling involves breaking down used plastic items into raw materials to produce new products (Singh and Sharma, 2016). Additionally, upcycling, which extends the useful lifespan of materials or repurposes them for new functions, has gained recognition as a valuable approach to managing plastic waste. Upcycling allows waste materials, including plastics and EPS, to be transformed into new products without compromising their quality (Caldera *et al*., 2022; Tejaswini *et al*., 2022).

Literature has however shown that there are worries about the application and adoption of the different aforementioned strategies towards the management of EPS, among other plastic wastes. Across European Union countries, as assessed by Okan *et al*. (2019), waste management strategies vary widely, with some, like Germany, the Netherlands, Belgium, and Austria, excelling in recycling and energy recovery. Conversely, some countries, such as Croatia, Malta, Bulgaria, and Romania, still rely heavily on landfilling, which is both space-intensive and environmentally damaging (Chaudhary and Vijayakumar, 2020). This highlights the need for more effective waste management practices. Regarding the recycling of EPS, two primary approaches are discussed: solvent-based and mechanical approaches (Schyns and Shaver, 2021). While recycling EPS aligns with sustainability goals, it can be costly compared to producing new EPS. The solvent-based approach, while effective, can lead to carbon emissions unless plant-based oils are used. However, the latter can be expensive. The mechanical approach involves compressing the foam to remove gas, but this approach also has its drawbacks. Although Changwichan *et al*. (2018) claim that 100% mechanical recycling always showed the highest eco-efficiency (E/E) values for all types of plastic and bioplastic wastes; Gibson and Warren (2017) are of the opinion that using recycled EPS for surfboard production, the recycling process still requires energy to blow the EPS into a surfboard blank, hence generating carbon emissions and impacting the environment. Recycling remains an important but challenging avenue for addressing EPS waste, given that it is generally more expensive compared to using new EPS (Chaudhary and Vijayakumar, 2020), which has contributed to continued EPS production. Thakur *et al*. (2018) and Kumar *et al*. (2021) highlight the significant environmental impact of improper waste management, such as landfilling and incineration, which release harmful pollutants like CO_2 (Vollmer *et al*., 2020) and contribute to climate change. In fact, the European Commission has set the agenda for zero landfilling by 2025 (Thakur *et al*., 2018). The disadvantage of landfilling according to Thakur *et al*. (2018) is that it requires a lot of space and pollutes the environment; while the disadvantage stated for incineration is that carbon dioxide, toxic chemicals and harmful ash are formed after the incineration. Moreover, in developing countries, inadequate waste management practices pose a health hazard and threaten ecosystems (Chaukura *et al*., 2016). Addressing plastic pollution necessitates increased recycling rates and more sustainable recycling technologies, which consume minimal energy and avoid secondary environmental issues (Hahladakis *et al*., 2018).

There has been a global push to replace plastics like EPS with alternative materials. However, it is emphasised that such transitions should be based on comprehensive assessments that consider environmental footprints, production capacities, waste treatment capabilities, and logistics. Despite existing policy interventions in many countries and cities (Klemeš *et al*., 2021; Babayemi *et al*., 2019), strict enforcement and implementation of these policies remains a challenge (Klemeš *et al*., 2021). One promising solution explored is the development of multi-layered bio-composite materials to replace EPS. This material exhibits similar structural properties, such as density and bending modulus, to EPS but with superior impact resistance and reduced water sensitivity. However, its suitability for aesthetic and artistic purposes, such as intricate surface detailing, requires further investigation (Khademi, 2016). Additionally, adopting a Life Cycle Assessment (LCA) approach has revealed that EPS may not be as environmentally detrimental as commonly believed, especially when compared to other takeaway materials like aluminium or reusable plastics, depending on the number of uses (Gallego-Schmid *et al*., 2019; Tingley *et al*., 2015). Also, the growing call for the replacement of single-use plastics such as EPS with alternatives such as glass or metal wares will not necessarily impact the environment positively, as the transportation of these heavier options often leads to increased CO_2 emissions (Vollmer *et al*., 2020). This highlights the need to re-evaluate perceptions around single-use plastics. Nonetheless, EPS still poses challenges related to littering and harm to marine life. Recycling has been suggested as a means to mitigate these issues, but its impractical cost makes it less viable, leading to continued reliance on virgin EPS, against the mandate of the circular economy (Gallego-Schmid *et al*., 2019). Urgent action, including improved waste management and treatment, is called for to curb the plastic pollution menace in the environment (Lacerda *et al*., 2019). Furthermore, financing waste management through taxation on plastic imports, production, and use, is proposed as a means to address the burden of plastic waste and pollution, particularly in regions like Africa (Babayemi *et al*., 2019). Lastly, the importance of consumer behavioural change and reorienting attitudes toward the environmental impact of plastics is underscored as a crucial component of addressing the EPS problem and broader sustainability goals (Klemeš *et al*., 2020).

Conclusion

By and large, EPS stands as a material that bridges aesthetics, functionality, and creativity. With the adoption of techniques such as hand carving and carving using robotic tools like CNC, EPS offers a range of creative applications, both in process and product, across diverse fields and subdisciplines such as theatre, visual arts, puppetry, product design, architecture, and engineering. Thus, this review paper seeks to encourage further exploration and more environmentally responsible utilisation of the material among artists and designers. While some artists contribute to the development of a green society by using discarded EPS in their art, others contribute to the problem by choosing to use virgin EPS for their art because of benefits such as lightness versus optical weight, ease of carving, and cheapness of the material. Given the difficulty that accompanies the recycling options for EPS, its use in art has become another avenue for extending the material's end-of-life use. Therefore, this paper recommends that if artists must use EPS, then they should make it a point of duty to go for discarded EPS and other plastic wastes to help the environment.

Several areas that can be further explored in future research have also been identified. Firstly, since working with EPS is often a deductive and reductive process, what then are the strategies employed by artists and designers in disposing of, and (or) the reuse of unwanted EPS after carving a desired form from a block of EPS? This requires further enquiry by researchers to ascertain the creative industry's contribution to the plastic waste problem and (or) its effective solutions. From a historical perspective, the development and the commercialisation of EPS, which coincides with the Great Depression in the 1930s as captured in literature, requires further investigation to determine if the economic situation of the era is responsible for the widespread proliferation of the cheap material as an alternative to other more durable but expensive wares. The study went beyond its agenda to consider the environmental sustainability implications of the use of EPS not just for aesthetic purposes, but in a broader sense. A major finding in this regard is that EPS may not be as environmentally detrimental as commonly believed, especially when compared to other takeaway materials like aluminium or reusable plastics, depending on the number of uses. Thus, a more critical look at the economic and long-term environmental viability of the growing call for the replacement of single-use plastic is required.

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