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2MEOGA

Aggregates and Cuttings are Changing the Tiles Industry Worldwide with 3R Principle in the Face of Resource Depletion, Growing Demand, and Public Adoption. Seizing the Opportunity for this Evolving Industry is not About Just Jumping into the Space but Executing How to Satisfy the Customers to Create Value

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Graphical Abstract

Abstract

The global ceramic tiles market has experienced significant growth in recent years, driven by increasing construction activities, urbanization, and consumer demand for durable and aesthetically pleasing building materials. The market is estimated at USD 100.1 billion in 2021, anticipating growth to USD 210.3 billion by 2031, with a CAGR of 8.6% from 2022 to 2031. The principle of reducing waste, reusing and recycling resources and products is often called the "3Rs." Reducing means choosing to use things with care to reduce the amount of waste generated. Reusing involves the repeated use of items or parts of items that still have usable aspects. Recycling means the use of waste itself as resources. Several companies and research initiatives have successfully incorporated aggregate/mineral-based waste/ cuttings into sustainable tile production. Lithoverde® is the world's first texture to be truly described as recycled, 99% made up of offcuts of stone with the remaining 1% being a natural soy-based resin which is used as a binding agent. It uses 99% recycled stone aggregates compressed into high-end tiles. The tile industry has both B2B (business-to-business) and B2C (business-to-consumer) markets, with B2B focusing on sales to businesses like contractors and retailers, while B2C targets individual consumers for home projects. Waste-based tile market is valued at USD 7.92 billion in 2023, with projections indicating growth to USD 19.06 billion by 2032, reflecting a CAGR of 10.08%. Despite the potential, lack of customer education is a barrier for the evolving industry. The industry needs support to pivot strategies to include comprehensive customer education initiatives that empower the clientele and elevate service offerings. Many governments and the certification agencies that are helping the sector are also highlighted in the study. This strategic shift is not just beneficial—it is essential for the success and longevity of this business.

Keywords: *Certification, Customer Education, Government Support, Market, Tiles, Varieties of Tiles, Waste-Derived Tiles*

1.0 Introduction

The construction industry is considered to be one of the most important indicators of a countries economic state. Since concrete is the main and most widely used material in the civil engineering field, concrete production can be regarded as one of the biggest causes of both environmental pollution and excessive resource consumption. Consequently, on one hand, particular attention has been paid to the incorporation of different by-products and waste materials, such as fly ash, granulated blast furnace slag, and silica fume as cement replacements in order to decrease the amount of cement used, thus reducing the huge CO_2 emissions stemming from cement production.

Asia, particularly China and India, remains a dominant force in tile production and consumption. However, China's ongoing real estate challenges are expected to result in a slight contraction in demand and production. Conversely, India is poised for significant growth, with projections indicating an average annual production increase of 5.9% through 2028, adding over 800 million square meters in output during this period. Other regions, including Africa, the Middle East, non-EU European countries, and the Americas, are also expected to experience above-average growth rates, contributing to the industry's overall expansion.

The use of artificial aggregates manufactured from waste and by-product materials, as an alternative to natural aggregate, has attracted considerable research interest. This trend has many positive environmental consequences, including (1) the preservation of natural resources; (2) saving energy consumed by quarry processes; (3) converting waste into value-added products. One of the avenues for 3R (Reduce, reuse, and recycle) application involving aggregate and waste aggregate is to have tiles that can create value from the market. Despite the potential, tilespecific government support for waste-based tile production is somewhat limited across the countries.

2.0 The Market

The global ceramic tiles market has experienced significant growth in recent years, driven by increasing construction activities, urbanization, and consumer demand for durable and aesthetically pleasing building materials[1]. Estimates of the market's size and growth projections vary across different sources:

According to Straits Research, the market was valued at approximately USD 213.56 billion in 2024 and is projected to reach USD 399.28 billion by 2033, growing at a compound annual growth rate (CAGR) of 7.2% during the forecast period. GlobeNewswire reported a valuation of USD 248.89 billion in 2023, with expectations to reach around USD 420.65 billion by 2033, reflecting a CAGR of 5.39%[2]. Transparency Market Research estimated the

market at USD 100.1 billion in 2021, anticipating growth to USD 210.3 billion by 2031, with a CAGR of 8.6% from 2022 to 2031. These variations in market size estimates and growth rates can be attributed to differences in research methodologies, market definitions, and data collection periods. Nonetheless, the consensus indicates a robust and growing ceramic tiles industry worldwide[2,3].

Factors contributing to this growth include rapid urbanization, rising disposable incomes, and a growing preference for modern and stylish construction materials. Technological advancements in manufacturing processes and the development of eco-friendly products have also propelled the market. The Asia-Pacific region, particularly countries like China and India, has been a significant contributor to this expansion due to extensive construction activities and infrastructure development[4,5]. The global ceramic tiles market has been on an upward trajectory, with various sources projecting continued growth in the coming years, driven by both residential and commercial construction demands.

3.0 The Case of India

India stands as one of the world's largest producers and consumers of ceramic tiles, with its market experiencing significant growth in recent years. Several reports provide insights into the market's size and projected expansion,

- **Maximize Market Research** estimated the Indian ceramic tile market at approximately USD 5.18 billion in 2023, projecting it to reach nearly USD 9.54 billion by 2030, with a compound annual growth rate (CAGR) of 9.1% from 2024 to 2030.[4]
- **Grand View Research** reported revenues of USD 8.54 billion in 2023, anticipating growth to USD 13.27 billion by 2030, reflecting a CAGR of 6.5% from 2024 to 2030.[5]
- **Mordor Intelligence** projected the market size to be USD 10.45 billion in 2025, expecting it to reach USD 19.71 billion by 2030, with a CAGR of 13.54% during the forecast period.[6]

These variations in market size estimates and growth rates can be attributed to differences in research methodologies, data collection periods, and market definitions. Nonetheless, the consensus indicates a robust and expanding ceramic tiles industry in India[4,5].

Several factors contribute to this growth,

1) **Urbanization and Housing Development**: Rapid urbanization and expansion of metro cities have led to increased housing demands, boosting the need for ceramic tiles.
2) **Government Initiatives**: Policies focusing on housing and sanitation, such as the "Housing for All" initiative, have spurred construction activities, further driving tile consumption.
3) **Economic Factors**: Rising disposable incomes and a growing middle class have heightened demand for quality and aesthetically pleasing building materials.

India's ceramic tiles market is on a strong growth trajectory, driven by urbanization, supportive government policies, and economic development, positioning the country as a key player in the global ceramic tiles industry. Geographically, approximately 90% of India's tile production is concentrated in Morbi, Gujarat, making it a significant hub for both domestic supply and exports.

4.0 Applying 3R Initiatives

The 3R Initiative aims to promote the "3Rs" (reduce, reuse and recycle) globally so as to build a sound-material-cycle society through the effective use of resources and materials. It was agreed upon at the G8 Sea Island Summit in June 2004 as a new G8 initiative. In order to formally launch the 3R Initiative, it was also agreed to hold a ministerial meeting in Japan in the spring of 2005. The principle of reducing waste, reusing and recycling resources and products is often called the "3Rs." Reducing means choosing to use things with care to reduce the amount of waste generated. Reusing involves the repeated use of items or parts of items which still have usable aspects. Recycling means the use of waste itself as resources. Waste minimization can be achieved in an efficient way by focusing primarily on the first of the 3Rs, "reduce," followed by "reuse" and then "recycle." Mineral drill and polishing cutting waste comes in the right size to be used in the making of titles. The mineral waste cuttings that can be used in tile production. These waste materials, which come from mining, quarrying, and drilling operations, can serve as raw materials in ceramic or concrete-based tiles. Here's how:

1. Ceramic Tiles

a. **Replacement for Traditional Raw Materials:** Mineral waste can substitute feldspar, clay, or sand in ceramic tile manufacturing.

b. **Improved Strength:** Some mineral waste, like granite or marble dust, enhances tile durability.
c. **Lower Environmental Impact:** Using waste reduces the need for virgin raw materials and minimizes landfill disposal.

2. Concrete Tiles

a. **Binder and Filler:** Waste cuttings can be mixed with cement as a binder, reducing cement usage.
b. **Improved Aesthetics:** Stone-based waste can enhance texture and color variations.
c. **Cost Efficiency:** Reduces the cost of raw materials and promotes sustainability.

Waste cuttings must be chemically analyzed to ensure they don't contain harmful contaminants. Processing Requirements: Some waste may need grinding, sieving, or heat treatment before use. Regulatory Compliance: Must meet industry standards for tile strength, water absorption, and durability.

Using mineral waste in tiles is an innovative way to promote circular economy

Debris from construction, demolition, and industrial processes is one of the biggest waste streams in the world. In Europe, it accounts for approximately 35% of all waste generated. In countries like the United States and China, the percentage is even higher. Additionally, the construction industry is responsible for one-third of all CO_2 emissions in Europe. Several companies and research initiatives have successfully incorporated aggregate/mineral based waste/cuttings into sustainable tile production. Here are some notable examples:

4.1 Vein Tiles (StoneCycling, Netherlands)

The company is now known as Front and by experimenting with new, cutting-edge technologies, creating different types of building materials for a variety of applications, and developing dry-stack systems that can be disassembled at the end of their lifespan, they offer a range of WasteBasedBricks®[6,7].

- **Material Used:** Upcycled mineral and industrial waste (including stone, glass, and ceramic waste).
- **Process:** The waste is ground into a fine powder, mixed with binders, and shaped into high-end decorative tiles.
- **Sustainability Impact:** Reduces landfill waste and cuts down CO_2 emissions by using recycled content.
- **Application:** Used in high-end architecture and interior design projects.
- **Case: Skip Tile:** Such ceramic tile reduces CO_2 emissions by over 50%, is composed of at least 95% waste materials, and is 100% suitable for any design project (Figure 1).

WasteBasedSlips: The WasteBasedSlips are cut from the WasteBasedBricks, making them waste-derived and resource-efficient. They significantly reduce material usage while preserving durability and the aesthetic appeal of traditional masonry facades (Figure 2).

4.2 Neolith (Spain)

Neolith has created the raw material to build spaces for the future. Our sintered stone is material manufactured with 100% natural raw materials. Neolith is the result of great effort in innovation to meet our main goals: Zero Waste, the use of recycled raw materials and production with a neutral impact on the generation of CO_2. A material that allows us to build a future for everyone. 100% of the raw materials used for its products are all-natural. What's



Figure 1. Skip Tiles by Vein Tiles.

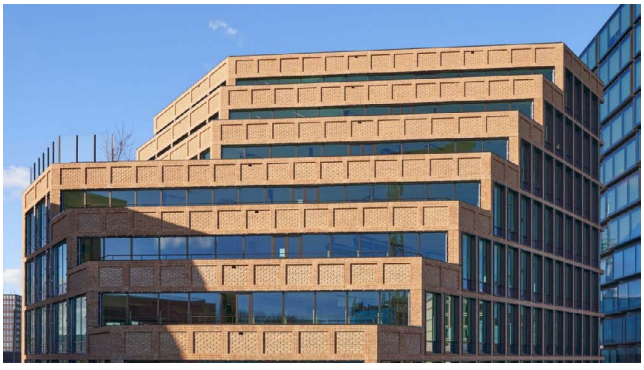


Figure 2. Waste-Based Slips.

more, up to 98% of those same raw materials are recycled, up to 100% of the water used in the production process is recycled and 100% of the electric energy used comes from renewable sources. Neolith is a revolutionary and innovative architectural surface, created with natural raw materials. It is the world leader of sintered stone and continues increasing followers among professionals and consumers. Neolith collections are suitable for any type of application, such as kitchen countertops, bathrooms, facades, floors and even furniture.

Benefits of Sintered Stone

Neolith surfaces can be used in any type of application and its technical characteristics make it a very versatile, elegant, and resistant material that offers infinite possibilities.

a. **Ultrahygienic**: Neolith is waterproof and resistant to liquids. It has an absorption level close to zero, which, combined with its large format where you can hardly see any joints, makes it a very clean material. Its special composition makes it resistant to most chemicals, and it is very easy to clean. In addition, the built-in NeolEAT technology helps prevent the proliferation of food bacteria, which is very common in environments such as kitchens or dining rooms, making it a safe surface for contact with food.

b. **Very Resistant:** The sintered stone is resistant to scratches, high temperatures and UV rays thanks to the hardness of its surface. That is why Neolith colors are not distorted when the surface is exposed to the sun or extreme weather conditions, making the material last for longer.

c. **Light and very Thin:** Lighter than many coatings or interior surfaces, Neolith can be produced in various thicknesses, including an ultra-thin 3 mm.

d. **Versatile:** Neolith is well-known for the versatility of its surfaces. It can be both used in indoors and outdoors and can be applied to kitchen countertops, bathrooms, facades, floors and even for creating exclusive furniture or decorative elements.

e. **Design:** The wide variety of colors and textures of the product, inspired by natural elements such as marble, stone, metals or wood, makes unlimited design possibilities and combinations. In addition, Neolith provides elegance and beauty, adding up personality and distinction to every space where it is applied.

Material, Process and Impact: Up to 98% recycled raw materials, including are crushed stone and quarry waste. The waste is processed under extreme heat and pressure to create sintered stone surfaces. It requires less quarrying of natural stone and follows eco-friendly manufacturing processes. These are used in countertops, floors, walls, and facades.

For more details please see: https://www.neolith.com/

4.3 ECOPact Tiles by Holcim (Global Initiative)

Recycled aggregates from demolition waste, quarry waste, and industrial byproducts are used to make tiles. The material is mixed with low-carbon cement to create sustainable construction tiles. It reduces cement consumption and promotes circular construction. These are used in both B2B and B2C markets for eco-conscious building projects.

5.0 Tiles Made from Aggregates

Innovative binding techniques make tiles made entirely from aggregates (without ceramic or cement-based binders) possible. Resin-bound tiles and paving are made by a mixture of aggregate stones and resin used to pave footpaths, driveways, etc. They are a kind of permeable paving solution. Resin is a flexible surfacing material, so it is resistant to cracking. The system is mixed on-site and cold applied, using a high-quality clear UV-resistant resin binder to coat the aggregate particles prior to laying. Unlike resin-bonded surfacing, where a thin layer of resin is applied to the surface and then the aggregate scattered on top (which can then become loose over time and is impermeable), resin and aggregates are thoroughly mixed together prior to laying, ensuring that the aggregate is completely coated and so providing a bound surface.

Here are some sustainable examples and methods:

5.1 Resin-Bound Aggregate Tiles

Resin-bound paving is a mixture of aggregate stones and resin used to pave footpaths, driveways, etc. It is a kind of permeable paving solution. It is a flexible surfacing material, so is resistant to cracking. The system is mixed on site and cold applied, using a high-quality clear UV resistant resin binder to coat the aggregate particles

prior to laying. Unlike resin-bonded surfacing, where a thin layer of resin is applied to the surface and then the aggregate scattered on top (which can then become loose over time and is impermeable), resin and aggregates are thoroughly mixed prior to laying, ensuring that the aggregate is completely coated and so providing a totally bound surface. 100% crushed stone, marble, granite, or other aggregate waste, are bound together with eco-friendly resins. Aggregates are graded for size and mixed with bio-based or low-VOC resins. The mixture is pressed into molds and cured to harden. It reduces reliance on cement and minimizes waste disposal. The tiles are used as After floor in (Figure.3) pavers, decorative wall tiles, and non-slip flooring.

5.2 Sintered Aggregate Tiles (Heat-Bonded Tiles)

The sintering method, which is mainly based on atomic diffusion, is a common application for mass production of lightweight aggregates without the requirement of long-term curing periods. The artificial aggregates should have high strength and low density, and the aggregates should bond strongly with the cement matrix. Generally, sintered aggregates are manufactured using fly ash due to its massive production of approximately 15 million tons per annum from a wide variety of industries. The fly ash-based sintered aggregate is generally manufactured at the sintering temperature ranging between 900 and 1200 °C. The properties of artificial aggregates are significantly affected by the binder types and amount.

1. **Material:** Crushed quarry waste, natural stone cuttings, or industrial mineral byproducts.
2. **Process:**
   - High-pressure pressing forms tiles without the need for cement.
   - The tiles are heated at high temperatures (~1,200°C), causing natural fusing of particles.
3. **Sustainability:** No need for chemical binders, high durability, and weather resistance.
4. **Use Case:** Heavy-duty flooring, facade cladding and architectural surfaces.

5.3 Alkali-Activated Aggregate Tiles (Geopolymer Tiles)

Alkali-activated aggregate tiles, often referred to as geopolymer tiles, are a sustainable alternative to traditional ceramic tiles, produced by reacting aluminosilicate materials with an alkaline solution to form a strong, durable material.

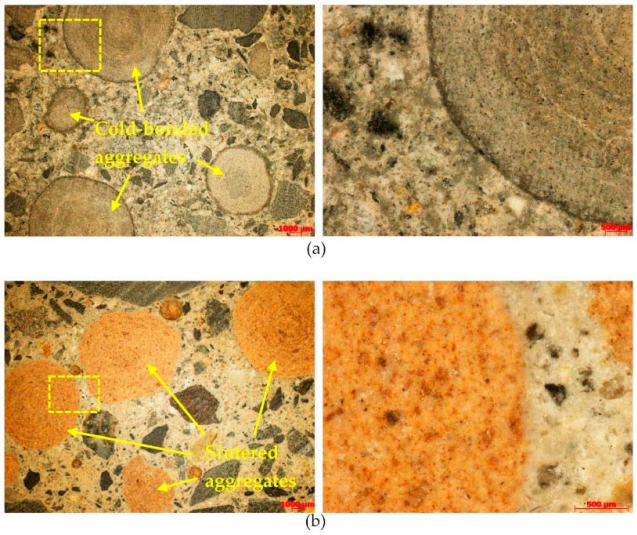


Figure 3. Examples of Cold-Bonded (a) and Sintered Aggregate.

5.4 Alkali-Activated Materials (AAMs)

Geopolymers are a type of AAM, which are binders produced through the reaction of an alkali source (like sodium or potassium hydroxide or silicate) and aluminosilicates. Common aluminosilicate precursors include metakaolin, calcined clay, slag, or fly ash. The process involves mixing the aluminosilicate material with an alkaline solution, which leads to the formation of a geopolymer, a type of inorganic polymer. Geopolymer tiles offer a more sustainable approach to tile production compared to traditional ceramic tiles, which require high temperatures and energy-intensive processes.

5.5 Advantages of Geopolymer Tiles

Geopolymer tiles can be highly durable and possess good compressive strength. Using industrial byproducts like fly ash or metakaolin as precursors reduces waste and lowers the environmental impact of tile production. Geopolymer tiles can be produced with various colors and textures, offering design flexibility. Geopolymer tiles can be more cost-effective than traditional ceramic tiles, especially when using readily available industrial byproducts. Geopolymer tiles can be used for both floor and wall applications, offering a durable and aesthetically pleasing surface. Geopolymer technology can also be applied to

other construction materials, such as foam blocks and soil stabilization.

Alkali Activation: The process involves dissolving aluminosilicate materials (like fly ash, metakaolin, or even waste ceramics) in a strong alkaline solution (e.g., sodium hydroxide, potassium hydroxide, or sodium silicate). This reaction leads to the formation of an amorphous or semi-crystalline aluminosilicate polymer network, which is what gives the material its strength and durability. Geopolymer tiles offer a potential pathway for sustainable construction by utilizing industrial byproducts and reducing reliance on traditional cement production, which is energy-intensive and emits significant CO_2.

5.6 Compressed Aggregate Tiles (Zero-Binder, Ultra-Compacted)

As a polysaccharide, xanthan gum, used as a binder, can establish an interconnected network of hydrogels within the soil matrix, which entangles with clay particles to constrain their movement and retain water. In addition, the hydroxyl groups in the xanthan gum molecule can form hydrogen bonds with the oxygen atoms on clay mineral surfaces. Furthermore, the negatively charged carboxylate groups in xanthan gum molecular chains attract and bind with positively charged metal ions in the soil, such as calcium and magnesium, fostering electrostatic interactions. Xanthan gum has been proven to have promising results in enhancing the compressive strength, water retention capacity, and resistance to erosion and weathering of earth blocks. They are used as luxury tiles, outdoor paving, and eco-friendly flooring.

Notable Sustainable Examples:

1) **LITHOVERDE (Salvatori, Italy):** Lithoverde® is the world's first texture to be truly described as recycled, 99% made up of offcuts of stone with the remaining 1% being a natural soy-based resin which is used as a binding agent. Uses 99% recycled stone aggregates compressed into high-end tiles.Lithoverde® helps to increase the level of architectural sustainability of a building using LEED® rating points (established by the US Green Building Council). Not only is it environmentally friendly and extremely easy to install, but also a beautiful texture with every block resulting in a unique pattern. Also please see Figure 4.
2) **BRETONSTONE® (Breton, Italy):** BretonStone is a formerly patented technology, also known as vibro-compression under vacuum, developed by Breton S.p.A. in the early 1970s, used to produce mineral surface slabs, including quartz countertops, on an industrial scale. BretonStone technology is a manufacturing process that creates engineered stone slabs, primarily used for countertops and other surfaces, by combining crushed stone (like quartz) with resins and other materials. BretonStone technology enables the mass production of mineral surface slabs, making them widely available. BretonStone products typically contain a high percentage of natural stone (up to 93%), which contributes to their durability and resistance to scratches and chips.



Figure 4. Tile Bianco Carrara, Lithoverde.

Manufacturing Process

- **Mixing and Homogenization:** Raw materials, including crushed stone, resins, and pigments, are mixed and homogenized.
- **Compaction:** The mixture is then poured between paper sheets and compacted under pressure and vibration.
- **Curing:** The compacted slabs are cured in a curing chamber to solidify the resin.
- **Finishing:** Finally, the slabs are processed to achieve the desired surface finish, including smoothing, calibrating, polishing, and edge work. BretonStone countertops are known for their durability and resistance to scratches, stains, and heat.
- **Non-Porous:** The material is non-porous, making it easy to clean and maintain.
- **Aesthetic Versatility:** BretonStone offers a wide range of colors, patterns, and finishes, allowing for creative design possibilities. Please see figure 5 to get the technology schematic.

(For more please see: https://issuu.com/bretonspa/docs/breton_journal_pietra_20192020_versione_tedesco)

6.0 Production Methods or Sourcing Specific Aggregates

Several methods exist to produce tiles using only aggregates without cement or ceramic binders. Aggregates, by themselves, lack the inherent binding properties needed for tiles to maintain their shape and integrity. Tiles made solely from aggregates would likely be fragile and prone to cracking or crumbling under stress. Aggregates are porous, meaning they would likely absorb water, making them unsuitable for wet areas. Aggregates could be compacted under extreme pressure to create a dense, solid mass, potentially forming a tile-like structure. Vibrating the aggregates during compaction can help to achieve a more uniform and dense structure. Geopolymers, formed from the reaction of alkaline solutions with certain silicate materials, can act as a binder. Also, ground ceramic tile waste can be used as a raw material for geopolymer binders, offering a sustainable alternative. Research is exploring the use of recycled materials like waste glass, plastic, and other construction debris as aggregates or binders. Some natural materials, like certain types of clay or volcanic ash, could potentially be used as binders or aggregates.

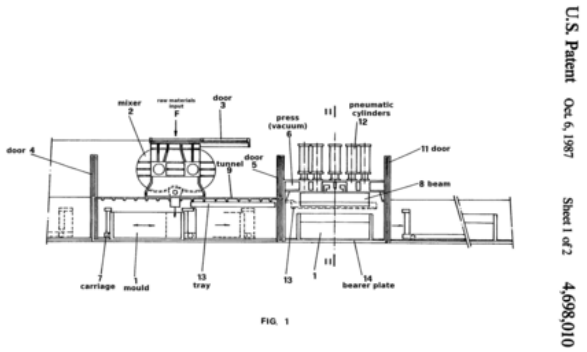


Figure 5. The tile technology schematic from the Patent (BretonStone technology).

6.1 Resin-Bound Aggregate Tiles

Resin Bound is a surfacing solution that results from mixing resin and aggregates together in a forced action mixer. This creates a mixture that can be trowelled onto a surface to provide a smooth, flat finish. A Resin Bound system is also known as 'stone carpet'. It also uses eco-friendly resin to bind crushed aggregates into tile form. For more please see: https://resinbondedaggregates.com/knowledge-centre/what-is-a-resin-bound-system

Process:

- **Aggregate Selection:** Choose stone waste (granite, marble, quartz, basalt, etc.).
- **Sizing & Grading:** Crushed aggregates are sieved into different sizes for uniform distribution.
- **Resin Mixing:** A bio-based or low-VOC resin (like epoxy or polyurethane) is mixed with the aggregate.
- **Molding & Pressing:** The mixture is poured into molds and pressed.
- **Curing & Finishing:** The tiles are cured at room temperature or under mild heat to harden.

6.2 Vitrified Aggregate Tiles (Glass-Bonded Process)

Vitrified tiles are similar to ceramic tiles in many aspects (Figure 6). However, they also contain silica and clay that melt and merge during the vitrification process to produce a glass-like element within each tile. This allows vitrified tiles to keep their original gloss for years to come,

imparting a great finish to its surface. These tiles are available in a wide range of shapes, designs, and colours, making them an attractive alternative to natural stones like marble or granite. Vitrified tile is slightly more expensive than other options because of the presence of silica and clay, as well as the vitrification treatment. This production process makes it highly non-porous at less than 0.1% of water absorption which makes the traditional cement usage for tile fixing redundant.

Method: Uses waste glass (silica) to bond aggregates at high temperatures.

Process:

- **Mixing:** Crushed aggregates + finely ground recycled glass.
- **Pressing:** The mixture is compacted into tile molds.
- **Firing:** Heated to ~1,200°C, where glass melts and binds the aggregates.
- **Cooling & Cutting:** Tiles are cooled and finished.

A table comparing the methods can be seen in Table 1.

7.0 B2B and B2C Markets

The tile industry has both B2B (business-to-business) and B2C (business-to-consumer) markets, with B2B focusing on sales to businesses like contractors and retailers, while B2C targets individual consumers for home projects.



Figure 6. A vitrified tile.

The B2B market is characterized by large volume orders, a focus on quality and durability, and long-term relationships with suppliers. The market may involve custom designs or specifications. B2B Market focuses on sales to businesses, including:

- Contractors: Who use tiles for construction and renovation projects.
- Retailers: Wholesale distributors and tile stores that sell tiles to consumers.
- Developers: Who use tiles in new construction projects.

On the other hand, the B2C Market focuses on Sales directly to individual consumers for home projects. They are of smaller volume orders, emphasis on aesthetics and design, a variety of tile types and styles, and direct interaction with consumers through retail stores or online platforms.

Examples:

1) **Tile stores:** Brick-and-mortar stores where consumers can browse and purchase tiles.
2) **Online retailers:** E-commerce platforms that sell tiles to consumers.
3) **Home Improvement Stores:** Large retailers that carry a wide selection of tiles.

Key Considerations

- **Marketing:** B2B marketing focuses on building relationships and demonstrating product quality, while B2C marketing emphasizes aesthetics and consumer appeal.
- **Distribution:** B2B often involves direct sales to businesses or through distributors, while B2C relies on retail stores and online platforms.
- **Pricing:** B2B pricing may be based on volume and long-term contracts, while B2C pricing is more competitive and often influenced by promotions and discounts.

Table 1. Comparison of Methods

Method	Binder Used?	Temperature Required	Strength	Sustainability
Resin-Bound Tiles	Resin (bio/low-VOC)	No	Medium-High	High
Sintered Tiles	None (heat bonds particles)	~1200°C	High	Medium (high energy)
Alkali-Activated Tiles	Alkali solution	No or low heat	High	Very High
Ultra-Compacted Tiles	None (only pressure)	No	Very High	Very High
Vitrified Tiles (Glass-Based)	Recycled glass	~1200°C	High	Medium (due to high energy)

For both B2B and B2C markets, the best production method depends on the available raw materials and target applications.

7.1 B2B Market (Construction, Industrial, Large-Scale Projects)

Recommended Methods:

- **Ultra-Compacted Aggregate Tiles**: Best for high-strength flooring, paving, and facades.
- **Alkali-Activated (Geopolymer) Tiles**: Sustainable alternative to cement-based tiles.
- **Sintered Aggregate Tiles**: Ideal for high-end commercial projects.

Why?

1. Bulk production scalability.
2. High durability for industrial and architectural use.
3. Cost-effective over large orders.

Target Clients:

Construction firms, architects, real estate developers, and infrastructure projects.

7.2 B2C Market (Retail, Homeowners, Small Businesses)

Recommended Methods:

- **Resin-Bound Aggregate Tiles**: Attractive, lightweight, and customizable.
- **Vitrified (Glass-Bonded) Tiles**: Water-resistant and stylish for home interiors.
- **Ultra-Compacted Tiles**: Premium natural stone look without cement.

Why?

1. Aesthetic variety for home décor.
2. Lower production costs for consumer pricing.
3. Eco-friendly appeal for sustainability-conscious buyers.

Target Clients:

Homeowners, interior designers, retail tile stores, showrooms.

Table 2 shows a table to choose the right methods etc.

Cost analysis

When comparing the costs and material preferences for tiles made entirely from aggregates versus those incorporating aggregate cuttings mixed with binders, several factors come into play, including material costs, production processes, and sustainability (Figure 3).

Table 2. Choosing the Right Method Based on Available Raw Materials

Raw Material	Best Method	Use Case
Marble/ Granite Waste	Resin-Bound, Ultra-Compacted	Luxury tiles, indoor flooring
Basalt, Quartz, Hard Stones	Sintered, Ultra-Compacted	Industrial & outdoor tiles
Quarry Dust, Fine Aggregates	Alkali-Activated, Vitrified	Large-scale, cost-effective
Glass Waste + Stone Chips	Vitrified, Resin-Bound	Decorative & waterproof tiles

Table 3.

Tile Type	Material Composition	Average Price (/sq.ft)
Natural Marble Tiles	Processed from natural Indian marble stone	60 - 90
Vitrified Tiles (GVT/PGVT)	Made from a mixture of silica and clay, fused at high temperatures	25
Ceramic Tiles (Double Charge)	Composed of natural clay and minerals, double-layered for durability	495.60 (per box)

Note: Prices are approximate and sourced from available market data.

1. Cost Comparison

Tiles Made Entirely from Aggregates

- **Production Method:** These tiles often utilize advanced techniques such as ultra-compaction or sintering, which may require specialized equipment and higher energy consumption.
- **Cost Implications:** The need for specialized machinery and energy-intensive processes can lead to higher production costs. However, the use of waste materials can offset some expenses.

Tiles with Aggregate Cuttings Mixed with Binders

- **Production Method:** Incorporating aggregate cuttings with binders like cement or resin is a common practice. For instance, replacing 20% of natural aggregates with waste ceramic tile aggregates in concrete has been explored.
- **Cost Implications:** This substitution can lead to cost savings. A study indicated that replacing 20% of natural aggregates with tile aggregates resulted

in a 16% cost reduction in producing M20 grade concrete.

2. **Aggregate Preferences for Sustainable Tile Production**
   - **Recycled Ceramic Tile Aggregates:** Utilizing waste ceramic tiles as aggregates not only reduces material costs but also promotes sustainability by diverting waste from landfills.
   - **Natural Stone Waste (e.g., Marble, Granite):** Repurposing waste from marble and granite processing can enhance the aesthetic appeal of tiles while contributing to environmental conservation.
   - **Industrial Byproducts (e.g., Fly Ash, Slag):** Incorporating industrial byproducts as aggregates can improve the mechanical properties of tiles and reduce the reliance on virgin materials.

In summary, while tiles made entirely from aggregates may incur higher production costs due to specialized processes, incorporating aggregate cuttings with binders can offer cost-effective and sustainable alternatives. The choice of aggregates plays a crucial role in determining both the environmental impact and the economic feasibility of tile production. Here's a comparison of tile prices based on different manufacturing methods and materials.

Considerations:

- **Material Costs:** Tiles made entirely from natural aggregates, such as marble, tend to be more expensive due to the cost of raw materials and processing.
- **Production Methods:** Tiles incorporating waste materials or alternative aggregates can reduce costs. For example, replacing 20% of natural aggregates with tile waste in concrete production has been shown to decrease costs by approximately 16%.
- **Market Variations:** Prices can vary based on factors such as brand reputation, quality, regional demand, and availability of raw materials.

In summary, while tiles made entirely from natural aggregates like marble offer premium aesthetics and durability, they come at a higher cost. Conversely, tiles incorporating alternative materials or manufacturing methods can provide cost-effective solutions without significantly compromising quality.

Economic Comparison of Waste-Based Tiles and Conventional Tiles with Market Sizes

The tile industry encompasses various products, including conventional tiles and those manufactured from recycled or waste materials. Below is an economic comparison of these segments, along with insights into their respective market sizes.

1. **Conventional Tiles**
   - **Ceramic Wall Tiles**
   - *Market Size:* Projected to reach approximately USD 315.1 billion by 2034, up from USD 144.6 billion in 2024, with a Compound Annual Growth Rate (CAGR) of 8.1%[8].
2. **Waste-Based Tiles**

Eco-Friendly Tiles

Market Size: Valued at USD 7.92 billion in 2023, with projections indicating growth to USD 19.06 billion by 2032, reflecting a CAGR of 10.08%. dataintelo.com+2marketresearchfuture.com+2market researchfuture.com+2

- **Recycled Plastic Tiles**
- *Market Size:* Estimated at USD 50.60 billion in 2023, with expectations to reach USD 70.26 billion by 2030, growing at a CAGR of 4.8%[9].

Economic Considerations

- **Production Costs**

1. *Conventional Tiles:* Typically involve energy-intensive processes, such as firing at high temperatures, contributing to higher production costs.
2. *Waste-Based Tiles:* Utilize recycled materials like plastic waste, potentially reducing raw material costs and energy consumption. For instance, tiles manufactured from plastic waste have demonstrated durability and cost-effectiveness compared to traditional tiles.

- **Environmental Impact**

1. *Conventional Tiles:* Production can lead to resource depletion and environmental degradation.
2. *Waste-Based Tiles:* Offer sustainable alternatives by repurposing waste materials, thereby reducing landfill contributions and promoting environmental conservation.

Market Dynamics

- The eco-friendly and recycled tiles market is experiencing significant growth, driven by increasing environmental awareness and regulatory measures promoting sustainability[10].

Table 4.

Country	TileSpecific Support?	Details
USA	Not specifically for wastebased tiles	Federal programs like EPA grants or DOE initiatives for wastetoresource conversion, along with various statelevel recycling and sustainable manufacturing funds, can sometimes be leveraged by producers.
UK	No dedicated tile program	Innovate UK and regional ecoinnovation grants support projects using recycled materials in construction; such schemes can be applied to wastebased tile production as part of a broader sustainability strategy.
Italy	Indirectly through industry innovation initiatives	The Italian ceramic sector benefits from EU funds and regional schemes (such as elements of the National Recovery and Resilience Plan) that encourage circular economy practices and sustainable manufacturing, which can include wastebased tiles.
France	Yes, under circular economy initiatives	The French Environment and Energy Management Agency (ADEME) and local subsidies support projects that convert waste into ecofriendly building materials, offering a pathway for wastebased tile producers to secure funding.
India	Not tilespecific but available through broader schemes	While India's ProductionLinked Incentive (PLI) scheme primarily targets general manufacturing sectors, statelevel recycling incentives and subsidies in the ceramics industry have been known to favor sustainable practices—including the use of waste aggregates in tiles.
Russia	No dedicated support for wastebased tiles	Government efforts focus on broad recycling and waste management policies, which may indirectly benefit wastebased tile production, though no specific program is identified for this niche.
China	Yes, regionally driven incentives	Local governments often provide tax breaks, lowinterest loans, and subsidies for recycling and sustainable building materials. Agencies under MIIT and environmental departments support projects that convert waste into construction products, including tiles.

- Despite higher initial investments in technology and processes for waste-based tile production, long-term benefits include reduced material costs and alignment with global sustainability goals.

In summary, while conventional tiles dominate the market, waste-based tiles are rapidly gaining traction due to their economic and environmental advantages. The growing emphasis on sustainability is likely to further propel the adoption and market share of waste-based tiles in the coming years.

8.0 Government Support

Despite the potential, tilespecific government support for waste based tile production is somewhat limited across the countries. In many cases, support falls under broader sustainability, recycling, and circular economy initiatives. Here's a summary overview,

The global market for tiles made from aggregates and waste materials is experiencing notable growth, driven by increasing environmental awareness and the push for sustainable construction practices. These eco-friendly tiles, often crafted from recycled materials such as reclaimed glass, ceramics, and natural stone, offer both aesthetic appeal and reduced environmental impact (table 4).

9.0 Market Growth and Projections

The eco-friendly tiles market was valued at approximately USD 7.94 billion in 2023 and is projected to reach USD 13.4 billion by 2030, growing at a compound annual growth rate (CAGR) of 7.3% during the forecast period from 2024 to 2030. This growth is attributed to several factors:

Environmental Awareness: Consumers and businesses are increasingly prioritizing sustainability, leading to a higher demand for building materials that minimize ecological impact.

Government Initiatives: Supportive policies and regulations promoting sustainable construction practices

encourage the adoption of eco-friendly materials, including tiles.

Technological Advancements: Innovations in manufacturing processes have resulted in high-quality tiles that are both aesthetically pleasing and functional, further propelling market growth[11].

Recycled Plastic Tiles Segment

A significant segment within this market is recycled plastic tiles. The global recycled plastic tiles market was estimated at USD 50.60 billion in 2023 and is expected to reach approximately USD 70.26 billion by 2030, with a CAGR of 4.8%. This growth is driven by factors such as,

- **Plastic Waste Reduction:** The increasing emphasis on reducing plastic waste has led to the development of tiles made from recycled plastics, offering a durable and eco-friendly alternative to traditional materials.
- **Sustainable Construction Practices:** The construction industry's shift towards sustainability has boosted the demand for recycled plastic tiles in various building projects. topprnews.com

Regional Insights

The adoption of eco-friendly tiles varies across regions:

Europe and North America: These regions lead in the adoption of sustainable building materials, driven by stringent environmental regulations and consumer preferences for green products[12].

- **Asia-Pacific:** Rapid urbanization and infrastructural development in countries like India and China are creating substantial demand for eco-friendly tiles. For instance, India's Kajaria Ceramics reported a decline in profit due to sluggish demand linked to heavy monsoon rains affecting construction activities. Despite the positive outlook, the market faces challenges:
- **Higher Initial Costs:** Eco-friendly tiles can have higher upfront costs compared to traditional options, which may deter some consumers.
- **Limited Availability:** The availability of these tiles can be restricted due to fewer manufacturers and suppliers.

However, ongoing advancements in manufacturing technologies and increasing consumer awareness are expected to mitigate these challenges, leading to broader adoption of eco-friendly tiles globally. The time series analysis projects that the aggregate and waste-based tiles global market will continue growing, reaching approximately $14.64 billion by 2030. Here are the projected market sizes for the next few years[13]:

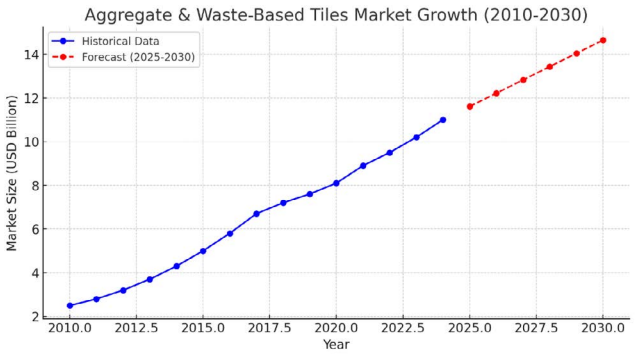


Figure 7. Aggregate and waste-based tiles market growth (2010-2030).

- **2025** → $11.61 billion
- **2026** → $12.21 billion
- **2027** → $12.82 billion
- **2028** → $13.43 billion
- **2029** → $14.04 billion
- **2030** → $14.64 billion

This growth is driven by increasing sustainability efforts, technological advancements, and government regulations promoting eco-friendly construction materials. A figure with time series analysis can be as in the figure 7.

10.0 Customer Education: Choosing the Right Tile

Despite the potential, lack of customer education is a barrier for the evolving industry. The industry needs support to pivot strategies to include comprehensive customer education initiatives that empower the clientele and elevate service offerings. This strategic shift is not just beneficial—it is essential for the success and longevity of this business.

To choose the right tile, consider the location, function, and desired aesthetics, opting for slip-resistant options in wet areas and durable materials for high-traffic areas, while also coordinating with other design elements and grout color. A few things are basic. Always ask for a test report from the manufacturer, verify certification marks before purchase, and choose tiles that meet your space's necessary strength, slip resistance, and environmental

requirements. Selecting the perfect tile for a factory, office or home requires careful consideration of aesthetics, functionality, and durability. Here is a basic guide to help make the best choice[11]:

1. **Understand Your Space and Needs**
   - **Home vs. Office:** Home tiles prioritize comfort and aesthetics, while office tiles need to be durable and professional.
   - **High vs. Low Traffic Areas:** Choose stronger tiles like **porcelain or vitrified tiles** for high-traffic areas.
   - **Wet vs. Dry Spaces:** Bathrooms and kitchens need **non-slip and water-resistant tiles** like ceramic or textured porcelain.
2. **Right Tiles**
   - **Ceramic Tiles:** Affordable, available in various designs, and easy to maintain.
   - **Porcelain Tiles:** Highly durable, resistant to moisture, and ideal for both homes and offices.
   - **Vitrified Tiles:** Low porosity, scratch-resistant, and perfect for high-footfall areas.
   - **Marble and Natural Stone:** Luxurious and elegant but require regular maintenance.
   - **Mosaic Tiles:** Best for decorative accents and artistic designs.
3. **Choose the Right Finish**
   - **Glossy Finish:** Reflective, stylish, and ideal for walls and low-traffic areas.
   - **Matte Finish:** Non-slip and best for floors, especially in wet areas.
   - **Textured Finish:** Offers grip and is ideal for outdoor or high-moisture areas.
4. **Color and Design Considerations**
   - **Light Colors:** Make a space look larger and brighter.
   - **Dark Colors:** Add warmth and sophistication but require more maintenance.
   - **Patterns & Designs:** Choose neutral patterns for offices, and creative, bold designs for home interiors.
5. **Size Matters**
   - **Large Tiles:** Create a seamless look, best for open spaces.
   - **Small Tiles:** Suitable for decorative accents and small areas.
6. **Budget and Quality**
   - Set a budget but prioritize quality and durability over price.
   - Compare different brands and check for water absorption rate, slip resistance, and wear rating.
7. **To be careful**
   - Always buy 10-15% extra tiles for future replacements.
   - Check tile samples under different lighting conditions.
   - Ensure proper installation for long-lasting results. Physical and chemical tests and certificates necessary?

11.0 Physical & Chemical Tests and Certifications for Tiles

When selecting tiles for homes or offices, it's essential to ensure they meet quality and safety standards. Manufacturers must conduct various physical and chemical tests to guarantee durability, safety, and performance. Here's a breakdown of the necessary tests and certifications:

11.1 Physical Tests for Tiles

These tests determine the strength, durability, and performance of tiles under different conditions:

a. Water Absorption Test
- Measures the tile's porosity.
- Low water absorption (<0.5%) is ideal for vitrified and porcelain tiles.

b. Strength & Durability Tests
- **Breaking Strength Test:** Ensures tiles can withstand load pressure.
- **Flexural Strength Test:** Measures the tile's resistance to bending or cracking.

Impact Resistance Test: Assesses how well the tile withstands sudden impacts.

c. Slip Resistance Test (Coefficient of Friction - COF)
- Ensures tiles provide adequate grip in wet and dry conditions.
- Matte and textured finishes usually have better slip resistance.

d. Surface Abrasion Test (PEI Rating)

- Determines resistance to wear and tear in high-traffic areas.
- **PEI Rating Guide:**

1. PEI 1: Walls only
2. PEI 2-3: Residential floors
3. PEI 4-5: Commercial and heavy traffic areas

e. Frost Resistance Test (For Outdoor Tiles)

- Tests tile performance in freezing conditions to prevent cracks.

11.2 Chemical Tests for Tiles

These tests ensure tiles can withstand exposure to chemicals, stains, and cleaning agents.

a. Chemical Resistance Test

- Checks resistance against acids, alkalis, and household chemicals.
- Essential for kitchen and bathroom tiles.

b. Stain Resistance Test

- Evaluates how easily stains (coffee, oil, ink) can be cleaned from the tile surface.
- **Glazed and polished tiles** perform better in this test.

c. Lead & Heavy Metal Test

- Ensures tiles are free from toxic substances harmful to human health.

11.3 Key Mechanical Tests for Tiles

a. Modulus of Rupture (MOR) / Flexural Strength Test

- Measures the tile's resistance to bending before breaking.
- **Test Method:** A tile is placed on two supports and pressure is applied at the center until it breaks.
- **Ideal Value:**

1. **Porcelain & vitrified tiles:** ≥ 35 MPa
2. **Ceramic tiles:** 12–25 MPa

b. Breaking Strength Test

- Determines the load a tile can withstand before breaking.
- **Test Method:** A force is applied evenly until the tile fractures.
- **Ideal Value:**

1. **Wall tiles**: ≥ 200 N
2. **Floor tiles:** ≥ 1300 N (for heavy-duty applications)

c. Impact Resistance Test

- Evaluates the tile's ability to resist damage from sudden impacts (e.g., dropped objects).
- **Test Method:** A steel ball or object is dropped from a height onto the tile.
- **Ideal Value:** Tiles should not crack or chip under normal conditions.

d. Deep Abrasion Resistance Test (For Unglazed Tiles)

- Measures surface wear due to friction.
- **Test Method:** A rotating steel disc with abrasive material is applied to the tile surface.
- **Ideal Value:** Vitrified tiles should have an abrasion resistance ≤ 175 mm^3.

e. Scratch Hardness Test (Mohs Hardness Scale)

- Determines resistance to scratches from sharp objects.
- **Scale (1-10):**

1. **Soft tiles (3-4 Mohs):** Suitable for walls.
2. **Medium hardness (5-6 Mohs):** Residential floors.
3. **Hard tiles (7+ Mohs):** Heavy-traffic commercial floors.

f. Thermal Shock Resistance Test

- Evaluates how well tiles handle sudden temperature changes (useful for outdoor and kitchen tiles).
- **Test Method:** The tile is heated to **100°C** and then rapidly cooled in water.
- **Ideal Result:** No visible cracks or damage.

g. Crazing Resistance Test (For Glazed Tiles)

- Checks for fine cracks (crazing) that may develop on the glaze over time.
- **Test Method:** The tile is subjected to repeated heating and cooling cycles.
- **Ideal Result:** No visible cracks under a microscope.

Specific Certifications for Mechanical Testing

Tiles should comply with global mechanical standards, including:

1. ISO 13006 & ISO 10545-4 (Flexural & Breaking Strength Test)
2. ANSI A137.1 (Mechanical Strength for US Market)
3. EN 14411 (European Standard for Ceramic Tiles)
4. SIS 15622 (Indian Standard for Strength & Durability of Tiles)

11.4 Necessary Certifications for Tiles

Certifications for tiles, like BIS (Bureau of Indian Standards) certification, play a crucial role in ensuring quality, safety, and enhancing consumer confidence

by verifying that tiles meet specific standards and requirements. They are done for the following reasons:

a. **Quality Assurance:** Certifications, such as BIS, ensure that tiles meet specific quality standards, including dimensions, water absorption, strength, and resistance to various factors like thermal shock and crazing.
b. **Consumer Confidence:** By carrying a certification mark, tiles gain credibility and build consumer trust, as it signifies that the product has been tested and meets established quality and safety standards.
c. **Market Differentiation:** Certifications can help manufacturers differentiate their products in the market, highlighting their commitment to quality and reliability.
d. **Compliance with Regulations:** Certifications ensure that tiles comply with relevant regulations and standards, which can be crucial for manufacturers who export or sell their products in different regions.

Tiles must meet international and national standards to ensure quality and safety.

ISO Certifications

- **ISO 13006:** Defines standards for ceramic tiles.
- **ISO 10545 Series:** Covers various tile tests, including water absorption, strength, abrasion, and thermal shock.

BIS (Bureau of Indian Standards) - IS 15622

- Required in India for ceramic and vitrified tiles.

CE Marking (European Standard)

- Mandatory for tiles sold in Europe, ensuring compliance with safety and performance standards.

ANSI A137.1 (American Standard for Tiles)

- Defines classification and performance requirements for ceramic tiles.

Green Certifications (For Eco-Friendly Tiles)

- **GreenPro Certification (India):** Ensures sustainable manufacturing.
- **LEED Certification (US):** Required for energy-efficient buildings.

12.0 Conclusions

Eco-friendly tiles Market Size was valued at USD 7.92 billion in 2023. The Eco-friendly Tiles market industry is projected to grow from USD 8.84 Billion in 2024 to USD 19.06 billion by 2032, exhibiting a compound annual growth rate (CAGR) of 10.08% during the forecast period (2024 - 2032). The growing demand eco-friendly tiles are due to eco-friendly nature and also due to the people's awareness of protecting nature from pollution. This study, while pointing out the potential, also points out the challenges the industry has and the support it requires.

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