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Building ceramics – raw materials, technology, and economic importance

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Abstract: The ceramics industry plays a key role in the economy, supplying materials essential for construction, electronics, metallurgy, and many other industries. In 2024, the production of ceramic products in Poland reached 118 million tons, including nearly 3 billion bricks and hollow blocks. The basic raw material for the production of building ceramics is clay rocks containing minerals such as kaolinite, illite, and montmorillonite. These deposits are found throughout the country, especially in the Świętokrzyskie, Częstochowa, and Tarnobrzeg regions. At the end of 2024, the balance of clay raw material resources was 2,014.6 million m^3, and extraction increased by 20 % compared to the previous year. The ceramic production process includes raw material preparation, forming, drying, firing, and quality control. Modern technologies focus on automation, heat recovery, and the use of secondary raw materials. Building ceramics are characterized by high strength, weather resistance, fire resistance, and aesthetics. They are used in the production of bricks, roof tiles, tiles, clinker, and structural elements in traditional and energy-efficient construction. Production based on local raw materials reduces CO_2 emissions and supports the regional economy. Thanks to its durability and environmental friendliness, building ceramics remain the material of the future, combining tradition with modern trends in sustainable development.

Keywords: building ceramics, balance, technology

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Introduction

The products of the ceramic industry form the basis for many other branches of industry and are indispensable in households. Ceramic binders and building materials are fundamental in construction. Refractory materials are key structural components for thermal equipment operating at high temperatures – without them, the coke and

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metallurgical industries could not exist. Glass products are essential not only in construction but also in the packaging, optical, and electronic industries, among others (https://maestrovirtuale.com/pl, 2025). Special ceramics form the foundation of the radio and electronics industries. Statistics best illustrate the production scale and the role of the ceramic industry in the national economy. The total production of ceramic goods in 2024 amounted to approximately 118,000,000 Mg. Additionally, 2,849,000,000 bricks and hollow blocks, as well as 94,000,000 m^2 of ceramic tiles and pavement slabs, were produced (National Geological Institute, 2025).

Traditional ceramics include products made from clay, silicate glass, and conventional types of cement. New branches of the ceramic industry use simple compounds as raw materials, e.g., magnesium oxide, zirconium dioxide, and aluminum oxide. Generally, the chemical composition of products from these new branches is simpler than that of traditional ceramics. This development results from the interaction between electronics and the machinery industry (Małolepszy, 2013).

The scientific objective of this paper is to analyze the current state and significance of building ceramics in Poland, including the assessment of raw material resources, extraction trends, and production technologies. The study also aims to evaluate the environmental and economic impact of ceramic production, comparing it to alternative construction materials.

The literature review was expanded to include recent research on sustainable ceramic technologies, resource efficiency, and life cycle assessment (e.g. Acampora et al., 2025; Amin et al., 2024; European Ceramic Society Report, 2024; ISO 14040:2020; ISO 17889-1:2021; Khadim et al., 2025; Müller et al., 2024; Ref. Ares(2014)75606 – 15/01/2014; Vaselnia & Aminian, 2024). Moreover, it should be emphasized that in the context of the Circular Economy, ceramic materials, both those originating from construction (e.g. ceramic rubble, bricks, roof tiles) and utility ceramics (e.g. sanitary ware, porcelain), can be reused (recycling, upcycling) or recovered (Ulewicz & Halbiniak, 2016; Ulewicz et al., 2021), which significantly reduces their environmental footprint throughout the life cycle (LCA).

1. Occurrence of ceramic materials

The primary raw materials for the production of building ceramics are various clay rocks, which, when mixed with water, form a plastic molding mass, and sands known as non-plastic additives. These are added to the clay material to improve the properties of the ceramic mass. The formed and fired products must meet specific physical and technical properties defined by standards. Clay and non-clay (non-plastic) raw materials often occur together in one deposit, forming layers or interbeds, or as independent accumulations (Małolepszy, 2013).

The range of ceramic building materials includes primarily: ceramic bricks and hollow blocks, roof tiles, tiles, clinker shapes and bricks, as well as ceramic pavements. Raw materials from some deposits are also used to produce glazed tiles, stoneware products, ceramic tableware, and similar goods.

The plasticity and moldability of building ceramics are due to the presence of clay minerals. Their amount varies across different rocks – only a few percent in loess but up to 100 % in clay. Typically, raw materials contain about 40 % - 60 % clay minerals. Other components include quartz sand and dust, feldspars, calcite, and dolomite. Calcareous raw materials may contain iron minerals, mica, and organic substances. Rocks composed of a single clay mineral are rare; most consist of several – kaolinite, illite, montmorillonite, and chlorites – in varying proportions (National Geological Institute, 2025).

Raw materials for building ceramics occur throughout the country and vary in origin and age. Currently, the most significant are Quaternary, Neogene, Jurassic, and Triassic deposits. Among Quaternary raw materials, the most important are lacustrine clays and silts, mainly found in northern and central Poland. Other materials include loess, glacial clays, alluvial clays, weathered clays, and sands. Among older deposits, the most valuable are Neogene clays (the so-called Poznań series) from southwestern and central Poland and Miocene marine clays from the Carpathian Foredeep in southeastern Poland. Jurassic and Triassic deposits occur near the Holy Cross Mountains, in the Częstochowa region, and in Opole Silesia (Bartnik & Moniewski, 2018).

High concentrations of clay deposits used for building ceramics, lightweight aggregate, and cement occur in regions such as Częstochowa, Katowice, and Tarnobrzeg (National Geological Institute, 2025).

According to the Regulation of the Minister of the Environment of July 1, 2015, on geological documentation of mineral deposits (excluding hydrocarbons) (Regulation of the Minister of the Environment, 2015), the limiting parameters defining clay deposits for building ceramics include: maximum documentation depth – up to exploitable depth, minimum deposit thickness – 2 m, maximum overburden-to-thickness ratio – 0.5, maximum content of grains >2 mm – 1 %, maximum marl content in grains >0.5 mm – 0.4 %, minimum drying shrinkage – 6 %.

2. Balance of resources and extraction of ceramic materials

As of the end of 2024, the total geological balance resources amounted to 2,014.648 million m^3 (approx. 4,029.296 million Mg). Compared to 2023, the resource volume decreased by 7.612 million m^3 (15.22 million Mg), or about 0.4 %. The status of clay raw material resources for building ceramics is presented in Table 1.

Out of 1,095 documented deposits of building ceramics, 56 (5.1 %) were active, 35 (3.2 %) were temporarily exploited, 220 (20.1 %) were unexploited but thoroughly examined, 74 (6.7 %) were preliminarily explored, and 710 (64.8 %) were abandoned.

The total industrial resources amounted to 56 deposits with a volume of 129.920 million m^3, representing 54.9 % of the total balance. Year-on-year (2023-2024), the resource level decreased by 3.3 %. Extraction in 2024 reached 1.297 million m^3 (Table 2), an increase of 0.269 million m^3, or 20.07 %, compared to 1.028 million m^3 in 2023. The largest extraction came from the Oleśnica deposit in the Świętokrzyskie Voivodeship – 0.179 million m^3.

Figure 1 shows the reserves and extraction of clay raw materials for building ceramics in Poland in 2014-2024.

Table 1. Clay raw materials for building ceramics (in thousand m^3) (*own work based on* National Geological Institute, 2025)

Name of the deposit	Proven reserves	Resources [thousand m^3]	
		geological	industrial
Lower Silesian Voivodeship	59	783,569	15,789
Kuyavian-Pomeranian Voivodeship	18	25,299	1,246
Lublin Voivodeship	117	92,628	6,908
Lubusz Voivodeship	36	37,643	2,628
Łódź Voivodeship	96	41,452	2,774
Lesser Poland Voivodeship	60	107,309	8,829
Masovian Voivodeship	118	98,231	15,673
Opole Voivodeship	41	61,070	8,232
Subcarpathian Voivodeship	151	160,826	5,149
Podlaskie Voivodeship	21	24,878	1,001
Pomeranian Voivodeship	26	34,236	5,332
Silesian Voivodeship	127	98,581	5,217
Świętokrzyskie Voivodeship	58	251,017	39,609
Warmian-Masurian Voivodeship	40	55,958	224
Greater Poland Voivodeship	105	111,916	4,549
West Pomeranian Voivodeship	22	30,035	6,760
Total proven depositions	1,095	2,014,648	129,920

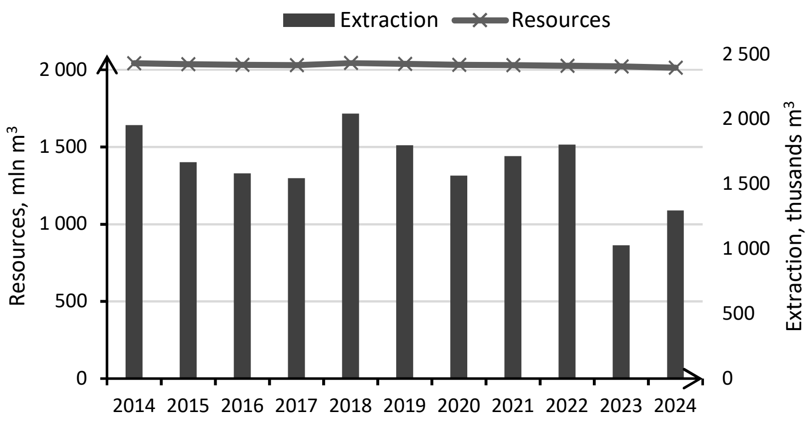

Fig. 1. Resources and extraction of clay raw materials for building ceramics in Poland, 2014-2024 (*own work based on* National Geological Institute, 2025)

Table 2. Extraction of clay raw materials for building ceramics (*own work based on* Central Statistical Office Warsaw, 2025)

Name of the deposit	Extraction	
	[Thousand m^3]	[%]
Świętokrzyskie Voivodeship	347	26.8
Lesser Poland Voivodeship	167	12.9
Lower Silesian Voivodeship	139	10.7
Subcarpathian Voivodeship	125	9.6
Masovian Voivodeship	120	9.25
Opole Voivodeship	76	5.9
Silesian Voivodeship	75	5.8
Lubusz Voivodeship	73	5.6
Lublin Voivodeship	59	4.5
Pomeranian Voivodeship	44	3.4
Greater Poland Voivodeship	40	3.1
Łódź Voivodeship	17	1.3
Podlaskie Voivodeship	13	1.0
Kuyavian-Pomeranian Voivodeship	2	0.15
Warmian-Masurian Voivodeship	0	0.0
West Pomeranian Voivodeship	0	0.0
Total	1,297	100

Based on the presented data, it can be concluded that despite the relatively stable level of documented resources, the number of active deposits remains low, indicating a need for modernization and sustainable management of extraction areas. The environmental impact of clay mining includes land degradation, alteration of the hydrological balance, and emissions from extraction equipment. However, rehabilitation measures, such as reclamation and water body formation, significantly mitigate these effects (UNEP, 2020; Zine et al., 2024). Furthermore, integrating environmental management systems (ISO 14040) into mining operations contributes to reduced carbon intensity and improved resource efficiency.

3. Technology of building ceramics production

The production process of building ceramics includes the following stages:

1. Raw material preparation – cleaning, crushing, and mixing with additives (sand, ash, quartz dust).
2. Forming – shaping with presses or extruders.

3. Drying – removing moisture at 80 °C - 150 °C to prevent cracking.
4. Firing – carried out in tunnel kilns at 900 °C - 1100 °C; this process determines color, hardness, and durability.
5. Quality control – testing for strength, water absorption, and frost resistance.

Modern technologies include heat recovery systems, process automation, and the use of recycled raw materials, which reduce the environmental impact of production (https://najtanszahurtowniabudowlana.pl, 2025).

Firing temperature is one of the most critical parameters affecting ceramic properties. Higher firing temperatures (above 1000 °C) typically result in lower porosity, increased density, and higher compressive strength, while lower temperatures may yield lighter but more porous products (Martínez-Martínez, 2023).

The forming method – extrusion, pressing, or slip casting – also influences the internal structure of the ceramic body. Extruded bricks, for instance, exhibit anisotropic pore distribution, which can affect frost resistance and water absorption.

The incorporation of additives such as fly ash, slag, or mineral fibers has become a sustainable strategy for improving performance and reducing energy consumption. Fly ash can reduce firing temperature and improve thermal insulation, while fibers enhance mechanical strength and crack resistance (Ayala Valderrama et al., 2021).

In terms of environmental technologies, closed-loop water systems, waste heat recovery, and the use of renewable energy sources (e.g., biomass and solar power) are increasingly adopted in modern ceramic plants, effectively lowering CO_2 emissions (Ref. Ares(2014)).

4. Properties of building ceramics

Building ceramics are characterized by (Małolepszy, 2013):

- high compressive strength (even >40 MPa for clinker),
- resistance to atmospheric factors,
- low water absorption and frost resistance,
- non-combustibility and fire resistance,
- good thermal insulation,
- color durability and high aesthetic value.

These properties make ceramics a durable, ecological, and environmentally friendly material (https://najtanszahurtowniabudowlana.pl, 2025).

In comparison to competing materials such as concrete, silicate, and polymer composites, ceramic products generally show higher durability and superior resistance to UV radiation and fire. However, they may exhibit higher production energy demand. According to EN 771-1:2015 and EN 1304:2013, building ceramics meet stringent mechanical and thermal performance standards, ensuring long service life in structural applications (Amin et al., 2024).

Table 3. Selected properties of building materials (*based on* EN 1304:2013; EN 771-1:2015; EN-538-1999)

	Density [kg/m^3]	Compressive strength [MPa]	Thermal conductivity λ [W/(m^2·K)]	Young's modulus [GPa]	Water absorption rate [%]	Frost resistance
Hollow brick/ceramic brick	1700-2000	2-10	0.08-0.44	10-40	to 8	≥ F100 cycles
Frost-resistant concrete	2300-2500	35-50	0.2-1.75	25-37	to 5	≥ F50 cycles
Ceramic roof tile	2000-2011	no data available*	0.17	50-70	below 0,5	grade I

* Bending load capacity 1200 N - 1500 N

Based on the data presented in Table 3, it can be observed that ceramic blocks and bricks exhibit significantly lower density and thermal conductivity compared to frost-resistant concrete, which indicates their more advantageous thermal insulation properties. Ceramic roofing tiles demonstrate the highest Young's modulus, reflecting their considerable stiffness and structural stability, while simultaneously achieving the lowest water absorption, which effectively limits material degradation during service. It is also notable that ceramic materials generally achieve higher frost-resistance classes than concrete despite their lower compressive strength, confirming the effectiveness of firing processes and the resulting reduced porosity.

5. Applications of building ceramics

Building ceramics are used in many areas:

- bricks and hollow blocks – for load-bearing and partition walls,
- roof tiles – as durable roofing materials,
- ceramic tiles – for finishing walls, floors, and facades,
- clinker and paving bricks – for small architecture and road construction,
- structural ceramics – for chimney and ventilation systems.

In contemporary architecture, there is a revival of natural ceramics – such as facing bricks and facade clinker – used in both traditional and energy-efficient construction (https://www.canva.com, 2025).

Currently, ceramic materials account for approximately 35 % of building wall materials used in Poland, 42 % of roofing materials, and 28 % of facade cladding, according to industry reports (Krawczyk, 2022). In contrast, alternative materials such as concrete tiles and metal sheets account for 40 % and 15 % of roofing materials, respectively. This indicates that ceramics retain a dominant position due to their longevity, aesthetic versatility, and thermal performance.

6. Ecological and economic importance

The production of building ceramics relies mainly on local raw materials, which reduces transport needs and CO_2 emissions. Ceramic products are non-toxic, durable, and fully recyclable. Modern plants increasingly use industrial waste and renewable energy, aligning with the principles of a circular economy. The ceramic industry also plays a significant role in regional development by providing employment and contributing to the stability of local economies (https://najtanszahurtowniabudowlana.pl, 2025).

Recent analyses show that the average CO_2 emission per tonne of fired ceramic product is 180 kg - 250 kg, depending on fuel source and kiln efficiency (Müller et al., 2024). The use of natural gas, biomass, or electric kilns can reduce this footprint by up to 35 %.

Economically, the Polish ceramic industry employs over 30,000 workers and contributes approximately 2.3 % to the national GDP (Central Statistical Office, 2025). The export of ceramic tiles and bricks increased by 8 % in 2024, while import levels remained stable, indicating growing international competitiveness.

Life Cycle Assessment (LCA) studies confirm that ceramics have longer lifespans and lower maintenance costs than polymeric or metallic alternatives, offsetting their higher production energy (ISO 14040:2020).

Conclusions

Building ceramics represent one of the oldest yet most forward-looking materials in construction. They combine tradition and innovation – from natural raw materials to advanced production technologies.

Thanks to their durability, aesthetics, and environmental friendliness, ceramics remain irreplaceable in modern architecture and construction. The industry's development toward energy efficiency and sustainability ensures that building ceramics will continue to play a key role in the future.

The comparative analysis of selected material properties (Table 3) confirms that ceramic construction products successfully combine low thermal conductivity, moderate density, and minimal water absorption, which together contribute to their superior thermal performance and freeze-thaw durability. The fact that ceramic materials achieve high frost-resistance grades even at lower compressive strength than frost-resistant concrete further highlights the significance of densified microstructure and optimized firing conditions. These observations reinforce the competitive advantages of building ceramics in applications demanding longevity, environmental resistance, and energy efficiency, underscoring their continued relevance in contemporary construction.

The research demonstrates that efficient raw material use, technological modernization, and integration of environmental management systems can significantly reduce the ecological footprint of ceramic production. Future directions include broader use of industrial by-products, optimization of firing processes, and digitalization of production control systems.

In conclusion, building ceramics not only maintain their leading role in the construction sector but also show strong potential for alignment with low-carbon and circular economy objectives.

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