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Review

Masonry in the Context of Sustainable Buildings: A Review of the Brick Role in Architecture

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Abstract: The process of combining various parts to create a structure is called building. The most effective and significant component of any construction is masonry. The Colosseum, buildings from ancient Greece and Rome, Central American buildings, and Mycenaean structures all used this material as one of their primary building elements. The oldest form is dry masonry of irregularly shaped stones. The ecological qualities of masonry, as a restorative material with a low impact on the environment, as well as the environmental control capacity of the massive wall, bring masonry back to attention as a suitable material for sustainable building in the context of current concerns for sustainable architecture. This article takes the form of a review of the journey of masonry as the primary construction material—from prehistoric structures to modern-day edifices. This article will go through the fundamentals of masonry construction to support its usage in structures throughout history and in many architectural styles, as a crucial representation of human construction in architectural history. This article aims to create a historical review, presenting masonry as an essential building material and assessing its role in the history of building materials.

Keywords: contemporary architecture; bricks; masonry; sustainable building materials

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Citation: Almssad, A.; Almusaed, A.; Homod, R.Z. Masonry in the Context of Sustainable Buildings: A Review of the Brick Role in Architecture. *Sustainability* **2022**, *14*, 14734. https://doi.org/10.3390/su142214734

Academic Editor: Jozef Švajlenka

Received: 18 September 2022
Accepted: 30 October 2022
Published: 9 November 2022

1. Introduction and Background

Adobe is the name given to the earliest-used bricks in the western hemisphere, initially by the Aztecs [1,2]. Durand and colleagues [3] affirm that the precipitation of calcium carbonate is common in soils (especially those in arid regions) and regolith's. Calcareous porous clay is also found in arid regions of the world, and is commonly mined in Central America, Mexico, and the southwestern United States. Manzanilla and co-authors [4] have concluded that the Pyramid of the Sun, which has stood the test of time, was created from adobe in the fifteenth century. Unlike modern bricks, the ancient one—adobe in other words—was square and flat (sides 30–60 cm, thickness only 3–9 cm).

Brick walls are typically used to create the outside walls of structures, parapets, interior partitions, freestanding walls, retaining walls, and other vertical construction elements (see Figure 1). One may define masonry simply as the art of building with bricks. It implies that there are two types of masonry—one of which is brick. It can be further sub-categorized as clay-work and cement work, with clay and cement used to fill up the joints and build walls. The strength of masonry is simply its ability to support the load imposed by the structural elements above it.

Figure 1. Brick different forms and structures.

In contrast, its ability to maintain its position under horizontal loading is referred to as its stability. The application of loads to masonry creates internal stresses and deformations. The brand of mortar and brick, the shape and size of the masonry materials, and the thickness and density of the mortar layers together determine the strength of the masonry.

Over the many centuries, brick has retained all its advantages. Technological progress has only improved the valuable natural properties of this material, making it harder and more robust [5]. Over the long period of its existence, brick-making techniques have remained the same. Clay was quarried by hand and kneaded with feet (it was referred to as 'underfoot'); molding was carried out by hand. Brick was dried under a canopy or in open areas only in summer and fired in temporary outdoor ovens lined with raw material. While it will be difficult to do adequate justice to the history of masonry in Persia, China, India, Indochina, and the Islamic world in a short chapter, it can be mentioned however that Islamic culture has achieved a level of mastery in the ornamental, creative and aesthetic use of bricks that has not been paralleled. When recalling Islamic architecture, one first imagines glazed-colored faience, which was used to cover onion domes and soaring minarets. However, glazed bricks and onion domes are later inventions. Early Islamic architecture drew on older traditions. Not far from the Iraqi capital of Baghdad today, there was a palace built of burnt bricks, which was ranked among the world's seven wonders. The art of brickwork by the Central Asian masters is evidenced both by the buildings themselves and by their domes, which, covering significant spans, existed for a long time in the seismic conditions of Central Asia. In many monumental buildings of that time, the only building material for walls, ceilings, and decorative patterned masonry was brick; plaster and cladding were not used. Ornamental masonry made up of large planes on the facade (for example, arched niches, friezes, tympanums) sometimes carried out with relief. Often, the reserve was created by cutting geometric (rhombuses, rings, parallelograms, etc.) or arbitrary curvilinear figures on the front surface of the brick. Today, only fragments of this monumental structure have survived near Baghdad, but even they make a stunning impression because there is the world's largest vault of baked bricks, spanning 25.3 m. Where there was a lot of natural stone in the form of building material, it was used in early Islamic architecture; in other cases, the builders resorted to the technologies of Sasanian and Byzantine masons. The most significant monuments of brick architecture of that time are the desert palace of the Omahids, namely Mshatta, built in Jordan 743–744 AC; the Ushaidir palace—a fortress in Iraq constructed about 750–800 AC, and the Great Mosque, built by Caliph al-Mutawwaki in Samarra 848–852 AC. Following Byzantine and Sasanian patterns, the bricks of these structures were most often square. Thick, beautifully decorated walls were built from unbaked and fired bricks [6]. In the world, traditional unreinforced brick architecture is no longer used in new construction. However, masonry's architectural history must be conserved; this necessitates structural study, because masonry has been the primary construction material in architecture from antiquity to the present [7].

2. History—The Evolution from BC to AD

2.1. Ancient Civilizations—Rome, Mesopotamia, Greece, and China

Thirty centuries ago, humans were already familiar with processing (hewing, grinding) unfired bricks and building various structures using them. At the same time, there was a transition from laying "dry" to laying on clay and, subsequently, around 1000 BC, to laying on lime mortar. Hamburg and Lorenzon [8] propound the idea that, in the second and first millennia BC, using mudbricks (sun-dried clay bricks) and adobes (clay mixed with straw), civilizations commenced in the construction of fortresses and palaces, as well as mansions. The bricks were introduced in cases where a paucity of unfired bricks was experienced. Initially, as mentioned, raw bricks were usually superimposed, one on top of the other, without mortar. They cohered to each other lightly, creating a monolithic masonry.

Suzan and colleagues [9] opine that in the clayey river meadows of the Nile valley in Egypt, about 150 centuries ago, people fabricated artificial bricks from clay using molds solidified by an admixture of chopped straw and camel dung. A technological quantum jump occurred when 'burnt brick' was invented around 4000 BC. [10], and this made it possible to produce bricks in different colors. Binici and colleagues [11,12] have referred to excavations in burnt-brick buildings that have been utilized for a very long period, as evidenced by their employment in Mesopotamia, Egypt, and other early centers of civilization. Almusaed and co-authors [13] have explained that the brick-makers who made the unburnt fiber tiles (alternatives to burnt bricks) simply soaked and kneaded clay soil, mixed it with various additives (straw, manure, chips, etc.) and, having densified it, solar-dried the mass. Raad Z.H. et al. [14] assumed that bricks were strong, did not break when dropped from a height of about 2 m, and did not get wet for 1–2 days when exposed to rainfall. Moisture resistance was the main disadvantage of the unburnt fiber tiles, which were thus unsuitable for wetter climates.

Bricks have the reputation of being the earliest construction materials, and the first ones—mud bricks—were molded and naturally dried clay bars. Adding small pebbles and straws to the raw materials was expected to increase strength and reduce shrinkage [15]. However, the approaches were vastly different from the Egyptians sometimes laying dried bricks into the wall on a liquid clay mortar, and the Assyrians gluing freshly molded material into a monolith. Greater strength facilitated the construction of more massive structures—palaces, temples, etc.—in combination with burnt brick, which conferred durability to the structures. Han et al. have noted that burnt bricks are standard features between structural frames in the building and construction sectors owing to their simplicity of use [16].

In ancient Rome, a hydraulic binder—pozzolana (the origin of the name can be traced to Pozzuoli in Naples)—was used for masonry mortar. Excavations in Babylon show that the part of the city east of the Euphrates—4 million m^2 in the area—was shielded by brick walls. When the Mesopotamian culture was at its peak, decorative brick walls were a common sight. Adamo and Almusaed refer to the processional route from the Ishtar Gate to the city of Babylon, built by King Nebuchadnezzar and rebuilt by the Persian king Darius I around 500 BC [17–19].

A Greek house with walls lined with raw bricks, dating back to 800–600 BC, was unearthed in Kamesh-Burden. However, southern Europe's large-scale use of ceramic bricks (59 cm long, and 4–7 cm thick) dates back to 200–100 BC. According to Giuseppe and co-authors, the raw materials for these bricks used in southern Europe comprised clay and resin. The practice began with unbaked bricks—the clay drying up in the sun's heat and hardening [20]. Rossi & Almusaed believe that the ancient Egyptians, who pioneered and mastered the art of firing bricks in kilns, checked the correctness of the masonry of the walls with a triangle, and that the bricks were worn on the yokes, and assert that they adhered to this method of construction consistently [21,22].

The history of Chinese building construction has gone through three stages. One is the era of the most ancient caves and various nests, and then the era of the coexistence of wooden houses and thatched houses. In China, fired bricks have been employed in construction for at least 2000 years. Since the middle of the 19th century, a new system has replaced the previous one in the brick manufacturing process. European red brick and other contemporary goods have progressively supplanted the distinctive Chinese blue brick [23]. After modern times, adobe houses and red bricks appeared. Accordingly, a building made of red brick is not susceptible to damage from wind and rain and is durable, even for a hundred years. One can talk of sintered (clay) and non-sintered (lime–sand and fly ash) bricks in China. The former is made of clay, shale, and coal gangue material and is subjected to mud treatment, drying, and roasting processes, according to Amin Al-Fakih and co-authors. When the Qin and Han dynasties ruled China 221–207 BC, architecture flourished, and with it, the technology, scale of production, quality, and diversity of bricks [24]. Most old homes, including those in the ancient city of Pingyao in Shanxi, Huizhou homes, the old courtyard in Beijing, and other conserved historical buildings, such as the Big Wild Goose Pagoda and the old city wall, are constructed of blue bricks. Blue bricks made up most of the materials used to build load-bearing buildings in ancient China [25].

Focusing on ancient Rome, we define the concept—opus maximum-layered masonry—referring to walls being made of layers of different materials, usually bricks alternating with each other. The brick facade included strips of baked bricks running along the entire depth of the wall. With all these types of masonry, it must be emphasized that the bricks were usually cut, that is, they were treated like stones. The bricks delivered to the construction site from the kiln were considered simply as blocks that could be trimmed (cut to the required size, in other words) in situ, before being laid into the wall. The Romans embellished brickwork with images, thus beautifying it even further. Nadali considers that sometimes they, "like the Babylonians", used bricks tapering towards one end, making the mortar layers' visible side thinner [26]. They were also very meticulous about the final processing of the mortar layer. After the masonry was completed, another layer of mortar was applied—a technique which in architectural/construction parlance is called 'additional grouting'. The mortar layers grid was to look as flat as possible, but sometimes beveled and concave mortar layers were made. As referred to earlier also, about three millennia ago, masonry started being fastened with mortar. Dabaieh and colleagues have pointed out that this 'fastening' was done with lime and was used not only for constructing fortresses/defensive structures but also for residential ones. Around this time, ancient Rome could also avail of sun-dried clay bricks [27].

The Romans disseminated the craft of brickmaking throughout the West. Baudin and colleagues have written about Roman bricks used in Norman and Anglo-Saxon buildings [28]. Wherever their campaigns took them, the Romans took the bricks with them. Their practical sense helped them immediately grasp the advantages of bricks for the construction of vaults, as several structures still testify. Brick, the material of choice for the Romans, automatically became one for the entire world, owing to their conquests and trading links. Stefani Dou and colleagues believe most Roman and Byzantine bricks were plates measuring 30 cm square, and between 2.5 and 6 cm thick. Various additions, such as fine and coarse aggregates or fibrous materials, were utilized to enhance their qualities. Due to their extensive porosity and matrix fissures, ancient bricks from those eras often had low apparent specific densities (1.5–1.8 kg/m^3), high absorption rates (13–30%), and average compressive strengths (5–20 MPa) [29].

2.2. Medieval Times

Medieval architects advanced much further than their predecessors from ancient cultures, and cleverly manipulated brick's structural and decorative possibilities in construction. Hvattum has written that along with patterned masonry, its combination with terracotta and majolica details was also popular and in vogue [30]. Europe assimilated all the experience of ancient humans and the millennia of the past into its societal structures, with brick entrenching itself firmly around the 4th century AD. At the end of the 10th century AD, with the revival of cities, 2–3-storied brick residential buildings were built with shops/workshops at the ground level. Patterned masonry bricks with embellishments on their surfaces and a strong shiny glaze became the trends of those times. However, these were affordable only to the affluent—kings, funded monasteries, and powerful feudal lords/landed gentry.

Yakovlev and co-authors have written that, in the 11–12th centuries, thin and heavy slabs of different sizes, called plinths, were used, before bar-shaped bricks became ubiquitous [31]. The plinth, however, is typically viewed as a symbol of the structure's elevation towards the sacred and its isolation from profane daily life, whereas in modern usage, a plinth is a lower, square slab that sits at the base of a column and symbolizes the base course of a building or the outward-projecting base of a wall. In Germany, brick-Gothic architecture dominated all through the 12th–16th centuries. The European brick cathedrals, but from the 10th through the 15th century, are significant tourist attractions in the places where they were built. While the English were the first to introduce mechanical brick making, pioneering developments happened in Germany. The first usable extrusion press was made by the Berlin-based manufacturer Schlickeysen in 1854; the first ring kiln was set up by master builder Friedrich Hoffmann (it was registered as a Prussian and Austrian patent in 1858). At the same time, clay-working machines, runners, vyaltsy, and pug mills were set up in different parts of the continent.

The first brick-making machines were steam-powered, and wood or coal was used to fire bricks [32]. With rapid industrialization and the establishment of the belt press and ring kiln (referred to earlier), the brick dimensions were stabilized (suitable for mass production). At about this time, spurred by the Industrial Revolution, a new type of brick—refractory brick—came into vogue, being for use in furnaces to withstand very high temperatures. By the beginning of the 17th century, bricks had become the first choice for residential buildings. Their dimensions had come closer to modern standards, though there were some minor differences among manufacturers. Discussions regarding a single standard size were held among builders and manufacturers. Joseph and Tretsiakova-McNally have stated that it was in the second half of the 19th century that it was possible to standardize the size of raw bricks [33]. Fiala and colleagues state that the best way to dress the mortar layers in brickwork (considering the thickness of the mortar layers) is with the following dimensions: $250 \times 120 \times 65$ mm [34].

In England, for example, we find the neo-Gothic style which dominates the cityscapes of the country even today [35]. In the neo-Gothic style of architecture, the practitioners often chose unflustered brick as a facing material. By this time, the industrial revolution had already sped up all the processes in the value chain of the bricks, including transport [36].

The prevalent perception of medieval architecture as distinct from Renaissance town buildings can be questioned [37]. Lombardy, France, and Germany were major hubs for brick construction in medieval times. Bricks were used increasingly often during the Romanesque, Gothic, and Renaissance periods. The northern European nations—particularly northern Germany, Belgium, Holland, Scandinavia, and England—are home to numerous magnificent brick structures constructed from hand-made bricks in different hues.

Although manufacturing roof tiles in Flanders may be traced back to the 10th century thanks to archaeological discoveries, how the process evolved to produce bricks is still unknown. More than just as a less expensive alternative to stone, the invention and spread of brick in medieval Flanders must be understood in the context of the vibrant, sustainable building industry in a heavily populated and urbanized region [38].

Just as the Romans took the brick to England (which they were ruling), the British, when it was their turn, took it to Canada, towards the end of the 18th century. In fact, Quebec, a French colony, had not been enamored of bricks at that time, as the French evidently had not taken a liking for it as much as the British did. Most of these bricks were first imported from the British Isles and were used as ballast to stabilize the tall ships that came to Quebec to stock up on wood. Bricks continue to occupy a place of pride in industrial architecture too. Manufactured inexpensively in different standardized shapes and dimensions, they are just perfect for the furnaces and chimneys. Industrial buildings compensate for their drabness by having decorative motifs and ornamental cornices made of an arrangement of bricks of various colors or sets of reliefs and projecting bands.

Modernists began using ordinary-shaped or modular bricks as a decorative element by abandoning traditional principles, forms, and materials in favor of more natural and dynamic ones. They conferred upon Art Nouveau buildings a calm naturalness and a strong sense of individuality. The division into structural and decorative elements of the building disappears; elements of load-bearing structures and material go to the facade, giving buildings a new dynamic. Expressionist architects developed their ornamental language with rough, sharp, and often pointed elements, as well as horizontal and vertical forms. Purposefully laying bricks achieved the liveliness of the facade's characteristic of brick expressionism in patterns and ornaments on most buildings' facades. Additionally, the masonry pattern could give the building a pronounced horizontal or vertical movement. The use of brick was dictated by the tension of the post-war period, climatic conditions, and the economic situation of the area where it was distributed—Northern Germany in the 1920s. Despite the decisive renewal of forms and designs, the rejection of older styles, and the use of new materials, modernism did not abandon the use of bricks.

3. The Contemporary Brick Masonry Techniques

3.1. Masonry in the Application and Conceptual Framework

The management of masonry building assets throughout their lifecycle has undergone a significant change recently because of technological advancements in brick manufacturing and application models, particularly in construction activities which aim to increase productivity during the building creation phases. However, the traditional manual labor method might have several drawbacks, such as a high rate of mistakes and its constituting a waste of time and money [5]. Today, many examples applied modern technology in building conception and construction. Many architects and designers took the initiative to re-evaluate embossed brickwork. Their projects include a database created using algorithms based on traditional national patterns. The relief of the facade is based on the rhythmic repetition of the most basic forms and is extremely simple to create, like conventional geometric patterns. They have embodied the notion that anybody may and should be able to utilize bricks for cosmetic reasons. Brick walls line the entry road of Sala, which was created by onion architects [39]. Their contours imaginatively framed the sky and were made "the old-fashioned way", without the use of computer calculations. If we refer to "old brick construction," we refer at once to red ceramic bricks, which for most of history was exclusively a building material. Architects valued its functionality—strength, and affordability—but did not pay much attention to the aesthetic aspects—appearance. Today, the situation is rather the opposite [40,41]. Brick remains a reliable material, but architects, builders, and sellers rely on the aesthetics of brickwork—smooth and corrugated surfaces, different colors, and decorative inclusions. Technology assists in adding aesthetic components while improving functionality. The task of building then at once becomes a science, a business, and an art.

3.2. Masonry within the Architectural Model

Many brick buildings worldwide have a charm not easily found in wooden or reinforced concrete structures. Brick architecture not only overcomes the most apparent disadvantage of wooden architecture—vulnerability to fire—but also has the advantage of creating a stylish appearance by incorporating curved lines (arches). In terms of fire, reinforced concrete construction can also meet the requirements, but many other attractive features are unique to brick construction. It can create a building of any stylistic orientation and architectural complexity, and one which is composed of several stories. Furthermore, if the building's façade has been precisely constructed with high-quality masonry, it does not require any additional finishing work.

Bricks have excellent abrasion resistance, and their high strength is due to their opposition to the adverse impacts of temperature and humidity. Unlike wood, bricks do not rot, being resistant to deformation and fungal buildup. American architect Louis Kahn once said, "It is the architect's responsibility to return each brick to its original position. The architect does not realize his dream but helps the brick realize his dream." Facing (facing, facade, finishing) brick has a high surface quality and a precise, regular geometry. In addition, there are numerous options for brick processing surfaces (smooth, wavy, rough, "antique", etc.). Mortar layers in such masonry are performed on ordinary and colored masonry mortars. Facade bricks allow you to create an original architectural appearance, harmoniously combined with the color of the roof, windows, landscape—the environment. Factories produce several types of facing bricks, as shown in Figure 2.

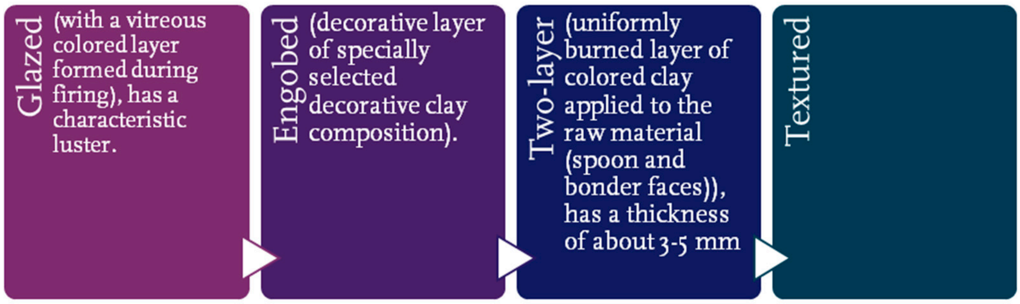


Figure 2. Facing brick types.

Most architects saw only a suitable constructive material in brick, mercilessly driving it into the thickness of walls or inside columns, hiding all its beauty under a thick layer of plaster. This was especially true of the facing of the monuments of the Renaissance, Baroque and Classical styles. In the middle of the 19th century, with a departure from the heritage of antiquity, turning to national traditions and searching for new ideas, architects turned their attention to this brick as a decorative element. Since the end of the 19th century, each new style has been given special meaning and function [42].

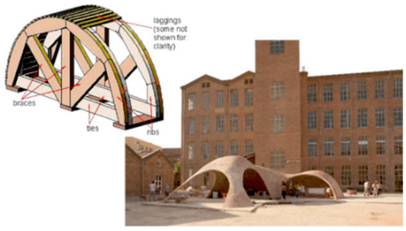
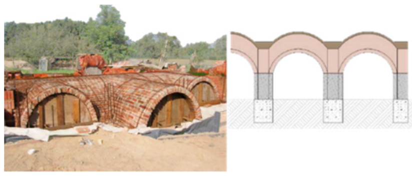
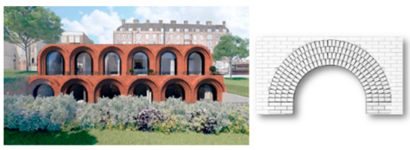
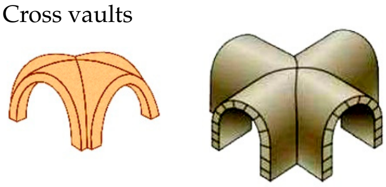
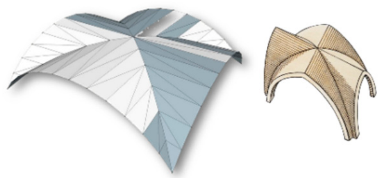
Finnish architect Alvar Aalto, for example, reimagined a brick building with the Muuratsalo Experimental House, which features over fifty types of bricks and masonry for the façade. This heterogeneous facade was also a testing ground for tracking the aesthetic possibilities of different bricks and their properties. Modernists also rejected the established association with brick as a material for heavy and monumental buildings. The façades of the famous Church of Christ in Uruguay and some other structures in the South American country were designed by Eladio Dieste, a modernist architect, in brick [43]. The main principles of organic architecture are freedom of spaces, deployed mainly in a horizontal plane, an endless combination of reinforced concrete and glass with more traditional and natural materials—wood, stone, and brick. In our postmodern era, brick is no longer used for decorative facades and is seldom used inside building structures. Instead, reinforced concrete, glass, and steel have supplanted its usage. Since the 1950s, masonry technology has remained virtually unchanged [44]. Some new solutions and additives improve the performance of a brick house—but the method of the masonry itself and the tools used are the same as more than half a century ago.

3.3. Brick Working Model

Firebricks are ideal if the masonry project aims to build a wall, framework, or building that is extremely heat- and fire-resistant. These bricks, also referred to as refractory bricks, are created from fireclay, a unique clay that mainly comprises silica and alumina. From the analysis of the bricks in action, bricks' fundamental physical properties are high compressive strength and low tensile strength (about 10% of compressive strength). As a result, they are unsuitable for tensile and bending components, thus preventing their widespread use in various structural systems. Sand–lime brick, invented towards the end of the 19th century, is now the undisputed classic among masonry bricks.

In recent years, there has been an encouraging trend toward improving the external appearance of buildings. Therefore, face bricks with various sizes, forms, colors, and textures have arisen. Table 1 displays several brick forms and shapes used in traditional and contemporary architecture.

Table 1. Bricks formed into arches and domes.

Form and Image	Description
Folded arch 	Based on the folded fake coupons, the Romans invented the real vaulted coupons in the 2nd century BC [45]. The coupon can be understood as the basic element of the arch. Single-story arched structures, such as arched doors and windows in the walls, are coupons.
Arch coupons 	The technique of arch coupons appeared in Mesopotamia as early as in the 4th millennium BC, and was later applied and developed in Babylon, Assyria, India, and Rome [46]. However, arch coupons appeared relatively late in China and went through several development steps of hollow brick beams and slabs, pointed arches, and folding arches, and formed in the early Western Han Dynasty.
Barrel vault 	The barrel vault is an extension of the coupon. Before the invention of concrete, barrel vaults consisted of multiple test blocks side by side. The original barrel-shaped vault was composed of numerous coupons juxtaposed and later developed into interlaced masonry between the coupons and connected into a whole, called a longitudinal barrel vault.
Dome 	The Romans created the dome arch from the tube arch structure, an alienated form of the barrel vault. The construction of domes is a millennias-old architectural tradition that persisted with several local variants worldwide [47].
Four-petal arch 	Like the quadruple arch, it is also crosscut on the square tube arch, which consists of four identical parts; however, the top forms a more distinct cross shape than the quadruple arch, so the Romans call it a cross arch.
Cross vaults 	Although the cross arch got rid of the load-bearing wall, it could not rely on its own structure to balance the side thrust like the four-petal arch and the barrel vault, so the Romans arranged the cross arch in the longitudinal direction, and the adjacent parts balanced the longitudinal side thrust with each other.
Rib vaults 	The ribbed arch appeared in the late Roman Empire. Compared with the cross arch, the ribbed arch is divided into load-bearing and enclosed parts. The main load is concentrated on the arch, and the rest is enclosed by light bricks slabs, saving materials and lightening the valuts top weight.

3.4. The Special Form of Masonry (Polychrome Brickwork)

Polychrome brickwork is a type of architectural brickwork that first appeared in the 1860s as a characteristic of Gothic Revival architecture. It uses bricks of various colors (typically brown, cream, and red) to create patterns and combinations that draw attention to specific architectural features [48]. It is frequently used to embellish windows and reproduce the Qu effect. Both early and later specimens have intricate diagonal, crisscrossed, and stepped designs, some of which are even inscribed in bricks. British architects like George Edmund Street and William Butterfield created several Gothic Revival churches and educational facilities in the 19th century, frequently including vibrant details. In his book *The Seven Lamps of Architecture*, art critic John Ruskin highlighted Tuscan and Venetian Romanesque and Gothic architecture as models for aesthetic qualities. One notable and eye-catching example is the Doge's Palace in Venice. This is attributed to architect Joseph Reid in Australia. Lisburn House in Dunedin, New Zealand, is the oldest instance of what can be referred to as a 'modern building'.

The 1870s saw the emergence of this style in England as well, as gathered from William Butterfield's work (a coincidental cooperation with Joseph Reed at St. Paul's Cathedral, Melbourne). Although there were some later examples, such as Watson Fothergill's work in Nottingham, it was not usually well acknowledged in the UK. According to Jonathan Foyle, the colorful brick art of many fake historic Australian homes and businesses was revitalized in the 1990s because of its relative simplicity and accurate replication of other faux landmark forms. It was frequently used for window ornamentation and to mimic the quoining look. Later specimens, some of which even used bricks, exhibited intricate diagonal, cruciform, and stepped motifs, in addition to the stripe that was present in earlier instances. English architects like George Edmund Street and William Butterfield created several Gothic Revival churches and educational facilities in the 19th century, frequently using polychrome. They did this during a 'period of yearning for the Middle Ages', if one could be permitted to think so. Apart from the obvious benefits that are considered when constructing load-bearing structures and walls out of bricks—durability, sound insulation, high thermal conductivity, affordability—ceramic bricks also provide other benefits [49].

3.5. Masonry & Quality-Control Process

The appearance of facing bricks constantly improves its properties over time and under the influence of solar ultraviolet radiation. Colors become brighter, and strength increases [50]. There is a certain fireplace brick—this is also a high-quality brick, but its surface may not be smooth. Next, there are shaped bricks—angular, semi-circular, or U-shaped. These lend easily to oval outlines, rounded corners, and special solutions for window frames, cornices, etc.

Bridge and facade clinker bricks, first made in Holland at the beginning of the 19th century, are now widely in demand in many European countries. The growth of cottage construction and elite housing, observed in recent years in Europe, makes it a necessary building material for us to examine. A good brick is distinguished by its homogeneity concerning quality. The entire batch ordered for constructing a house, whether a cottage or a multi-story building, will be completed as a single unit [51]. Bricks have a wide range of colors and textures. They have many types of size, including a very narrow brick, which in Europe is used to build cottages, apartment buildings, and churches. The construction of raw bricks was widely practiced: under the pressure of the structure, the masonry elements stuck together, forming a monolithic surface. Based on the use of raw bricks, the technology of firing clay bricks appeared; they were laid using strong solutions. Fired bricks were flat rectangular ceramic slabs, 31–65 cm in length and up to 10 cm thick. In [52], the thermal conductivity coefficients of refractory bricks are presented at different temperatures—from 20 to 1700 °C. This depends primarily on the density and configuration of the voids in the bricks.

Bricks are now often manufactured from a mixture of clay and sand in the proper proportions, held together with a binder. The bricks are frequently constructed from dirt pieces that have been stabilized using various substances. Furthermore, depending on the constructions' significance and the environmental conditions' severity, the bricks are described and categorized differently in several international standard codes. Therefore, for improved brick standardization, a complete analysis of the composition, characteristics, and other aspects of brick manufacture is essential [53].

4. Contemporary Masonry Construction Standards and Model

4.1. Masonry Working Standards

It is not easy to accomplish the goal of ecologically responsible building and construction without adopting eco-friendly goods and resources with a minimal carbon footprint [54]. Bricks have been recognized now as environmentally friendly materials for construction. The process is completely automated nowadays (it takes less than an hour). A workable mortar is used to bind construction materials—stone, bricks, and concrete—and to fill up any uneven spaces between them, distribute their weight uniformly, and occasionally paint ornamental designs on masonry walls.

Concrete hollow-block masonry is widely used in North American and Australasian countries because it enables grouting and reinforcement to resist higher axial and lateral actions, ultimately facilitating the construction of high-rise masonry buildings [55]. The difference between the models is mainly in their geometric shapes. Laying similarly does not show how it was set without using additional tools. To be picked up with one hand, bricks must be compact and lightweight. Conversely, the brick's width is determined by the acceptable grasp distance for most individuals, around 100 mm. The brick is short and ineffective at this length, while it is too tall and bulky. As multiples facilitate stacking, lengths, widths, and heights are frequently multiples of 4:2:1. However, regular bricks do not all have the same size. Figure 3 shows the variations in brick sizes among 10 countries.

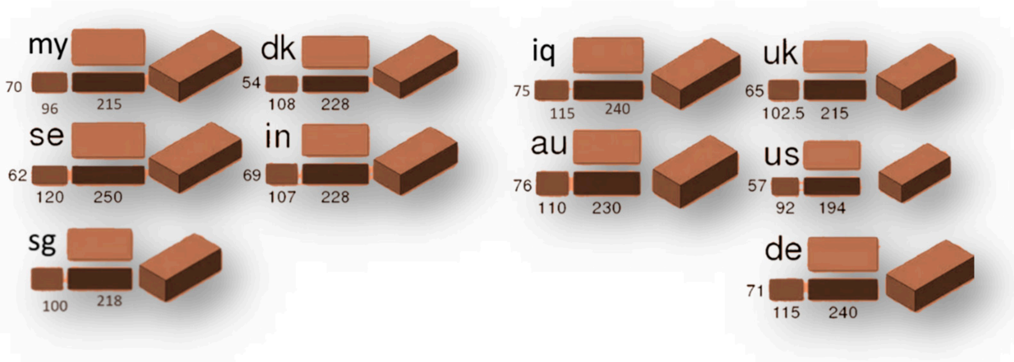


Figure 3. Shows the variations in brick sizes amongst nations [56,57]. (my = Malaysia; se = Sweden; sg = Singapore; dk = Denmark; in = India; iq = Iraq; au = Australia; uk = United Kingdom; us = USA; de = Germany).

Consider a structure composed of bricks. Figure 4 that shows red and rustic bricks are once again populated in modern construction. They appear to be 'gentle giants' or 'ancient wise rulers' in the contemporary cityscape, in contrast to the slick glass buildings. All the ideas displayed here use brick to give them a contemporary appearance while keeping a classic aesthetic that might add value or character to the structures. Over 300 choices in the color of the slinker enable one to realize even the most far-fetched architectural ambitions [58].

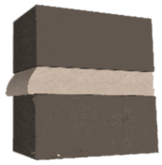
Figure 4. Bricks as an essential building material for modern architecture.

A wide range of colors is achieved by changing the firing technology—adjusting the temperature and volume of the air supply. Clinker—verily the material of the new millennium—is available in fiery nuances of red, radiant yellow, purest white or brownish blue. It is also bolstered by the ease of processing, increased wear resistance, low porosity, and high absolute frost resistance. Finally, there is a series of "Nostalgia" buildings—the bricks from them look like they were taken out of a wall three hundred years ago. The color of the European brick now can be just anything—shades of red and pink, indeed; but also black, white, and everything in between. The brick form we know today has evolved over time and has been shaped by several cultural and social influences of human beings in the past—both colonizers and the colonized, and at times even thanks to collaborations among these two classes [59,60]. Brickwork that satisfies the requirements of contemporary architecture and urban planning is reaching a new, better-quality level after decades of deconstructivism and hi-tech building. The various forms of mortar layers of brick buildings are tabulated in Table 2.

Table 2. Forms of mortar layers [61,62].

Type of Mortar Layers	Brief Description	Illustration
Flush form	Plastering and other final finishes are built using this mortar layer. As a result, these layers are finally concealed. It is somewhat time-consuming and requires a little more work. Water may settle on top of the flush form if it is made in such a way as to stand out from the brickwork.	
Raked form	The mortar is forced slightly inward in the raked jform, leaving it about 2 mm lower than the facing brick. Its ledge, which might enable water or snow to accumulate on top of the brick, makes it unsuitable for external usage.	
Concave form	It is one of the most common forms of mortar owing to the high amount of rainwater it can block, thus avoiding inward leakages. This layer's ability to keep the mortar tight is due to the employment of a curved steeling tool.	
"V" form	Named as such because of its "V" shape, as seen in the image on the right, this mortar layer offers little protection against water infiltration due to its design.	

Table 2. *Cont.*

Type of Mortar Layers	Brief Description	Illustration
Struck form	The struck form works better with interior walls than with exterior ones. This junction has a bottom edge that is recessed and a top edge that is finished flash with a brick edge. Water is drawn in and allowed to settle on the brick thanks to the slope of the layer	
Weather form	This is similar to the struck layer, except that the top edge is recessed, not the bottom. This junction allows the water to drain quickly from the mortar layer because of the slope. Additionally, the mortar in the mortar layer must be adequately bonded to reduce the likelihood of water seeping through its underside.	
Extruded form	No special tooling is needed for this kind of layer. Since excess mortar is naturally squeezed out, and causes an extrusion between the bricks, this effct is generated organically.	

4.2. Masonry, Form, Colors, and Selection Platform

Exposed brick walls are frequently hailed as being highly desirable to apartments, eateries, and retail establishments, and brick exterior facades can give a building or home a cozier, more inviting feel. On the other hand, white brick lends itself to a more minimalist style, while tan brick tends to seem more rustic and earthy. However, the color and cut of the brick may dramatically impact the ambiance of wall bricks, a typical construction material, being crucial to architectural aesthetics and a significant component of the architectural aesthetics framework. Color is key to how wall bricks look and may improve a building's visual appeal. However, differences in the color of the wall bricks will affect the overall appearance of the building (refer to Figure 5).

Figure 5. Assortment of textures and colors of bricks in contemporary architecture.

Three components determine the color. Let us start with the clay. This establishes the foundation color or the viewed colors. According to a study by Sedat and colleagues [63], the reddening of clay bricks was the primary cause of the color difference that appeared after 975 °C, as shown by the relations between temperature and each redness index and color difference. Hue and firing temperature showed a solidly negative correlation. Therefore, the hue was the essential color factor in describing the variation in clay brick strength (R^2 = 0.88), and it could be used as a quality indicator for clay brick strength. The next in the order of influencing color are the sand, engobes, and mineral pigments used to coat the brick's surface [64,65].

When bricks are baked in a kiln, their chemical composition changes, iron oxide is formed, and the color becomes reddish. The third influencing factor is the temperature in the kiln. A higher iron content renders the brick pink; the variations in the firing temperature impart different shades of red. Finally, a yellow or white color is due to the excess lime content. Bricks made of yellow clay were given a technological boost by using two wastes as supplementary source materials. The first is pyrrhotite ash, a mineral waste available for free. The second waste, cedar sawdust, comes from the artisanal sector and is organic. Yellow clay bricks with varying waste contents were made, tested, and evaluated for their technological characteristics, including water absorption, bulk density, porosity, and mechanical strength [66].

In general, as bricks are made in open-air kilns from fired clay, which contains iron oxidized to ferric oxide (high oxygen content, and dark red) at 1000 °C, they are red. On the other hand, in closed kilns (kilns with roofs) with less oxygen, the fired bricks are blue. Because all the green brick kilns have roofs and this type of dome cannot be created as a primary structure, the output of ecological bricks is significantly smaller than that of red bricks. Consequently, bricks which are greener than red bricks are made; green bricks are more robust and denser than red bricks. Therefore, according to the quality of the building, the ancients chose blue bricks.

4.3. ABC and Sustainability

In the ABC (architecture, building and construction) development process, masonry buildings have become a symbol of sustainable buildings in terms of their operational energy and/or material usage [67]; where over the last two centuries, technology has advanced tremendously, this has resulted in a significant depletion of non-renewable raw materials and a rise in hazardous (climate-change-inducing) emissions [68]. Therefore, building direction in the construction industry implies a substantial application of sustainability. Modern developments have made it possible to widen the selection of renewable building materials and perfect these sustainable building materials in terms of external, technical, and technological parameters. Sustainable construction is the current paradigm in the ABC sector (architecture, building, and construction), both in European and non-European contexts [69]. It is becoming increasingly crucial for the overall healthy functioning of society and the entire environment, according to the global trend of the construction business. The modern-day 21st-century brick has all the properties of natural building materials: strength as well as water-, and frost-resistance (degree of resistance to freezing and thawing, measured in a test chamber).

Additionally, they are becoming more and more eco-friendly, as industrial and building material wastes are now increasingly used to make bricks instead of cement, clay, or sand [70]. Voidness is another property of ceramic bricks. The marking often denotes whether the brick is porous or solid; that is, whether its body contains voids in the form of through-holes of different shapes. These bricks have less thermal conductivity than the non-porous ones, hence exterior walls are composed of porous bricks, where they provide greater thermal insulation than those consisting of solid bricks. Voidness though does not have an adverse impact on its strength. A porous brick, it follows, cannot be utilized in furnaces.

Brick manufacturing has produced a variety of goods depending on the intended use, including brick that is painted in volume, chipped full-bodied and fronted with a relief surface, hollow and covered with unique polymers, etc. Brick is one of the most popular building materials for multi-story public and private structures because of its diversity and durability. Today, clay bricks face technological challenges, and are non-competitive, vis à vis materials like concrete. Although the core technique for making burnt bricks has not changed much through time [71], the technology used to execute it has advanced tremendously. In contrast, a unique brick called eco-brick may be used as a low-cost building material and recycling alternative in places without commercial recycling facilities. Eco-brick is formed of recycled polyethylene terephthalate (PET) bottles that have been filled with mixed inorganic rubbish [58]. The result is a brick without inclusions and voids. This technology guarantees high strength and durability. Clinker is widely used for paving paths, facing plinths, and facades. In addition, it finds use in car parks and entrances to garages, open terraces, stair cascades, drains, and patios, in perfect combination with the foliage of the lawns and the architectural details of the garden landscape. Clinker easily withstands even the most adverse weather conditions, retaining its natural color, and does not require additional maintenance expenses for decades.

Contemporary brick production is carried out in high-tech, automated, and often robotized setups. For example, brick-laying robots have been programmed to construct a wall using cinder blocks autonomously [72]. All this however depends on, and necessitates, meticulous raw material selection, exact adherence to technological requirements, and computer-aided product quality evaluation. Unlike other traditional materials such as wood and different forms of bricks, which were supplanted by new materials (steel, concrete, etc.) as the 20th century progressed, brick adapted to changes and has retained its place in architectural history. For example, with the Art Deco trend, yellow brick entered the construction of several modern buildings with clean lines; and glazed, textured, or polychrome bricks have become popular in modern-day churches. In addition, the North American bungalows that have sprung up by the thousands in the suburbs of our cities have given pride of place to the versatile brick, thanks to the legendary American architect Frank Lloyd Wright.

5. Conclusions

Masonry is a difficult and multifunctional building material. It became even more important to use materials that complied with the building's environmental requirements once the objective of creating a sustainable structure was established. Bricks was once more an obvious option due to its exceptional durability. One of the first materials created by humans, its use goes back to 7000 BC. It is vital, resilient, and weathers well. It is a defining feature of some of our most prized examples of old architecture and helps to create an atmosphere that people feel is permanent and secure. It is, by nature, a more ecologically friendly substance than many others. The Industrial Revolution brought about a significant rise in output, with bricks replacing stone as the material of choice. The most general sense used to make bricks is clay. However, concrete and calcium silicate are also occasionally utilized, and their production is now more effective than before. Due to their large thermal mass, bricks used in sustainable construction can aid in reducing interior temperature changes. Nevertheless, they also have low embodied carbon.

The pioneers in firing bricks were the Egyptians: on the frescoes dating back to the times of the pharaohs, one can observe and get an idea about how the process of making bricks and using them to build structures took place. The difference between ancient and modern Egyptian construction is slight—the Egyptians used a yoke to carry the bricks, and a triangle checked the correctness of the brickwork. The principle of building structures has changed little since then. In the West, in ancient times, flat and square adobe bricks were in vogue—made from porous lime clay with the addition of minerals like quartz and resin. The Aztecs built the ancient Pyramid of the Sun solely out of these bricks, and it has stood the test of time while still looking as stunning as it would have to these original inhabitants of South-Central America. This article undertakes a review from the ancient ages to modern times. It follows the history of bricks as primary building materials, their significance in different architectural styles, their applicability in contemporary architecture, and projects of various types, including private and public facilities in multiple climes. It also briefly discussed the typical varieties of decorative brickwork, the benefits, and characteristics of its use in improving the external appearance of buildings and thereby the urban environment, the practical justifications for the same, the objectives accomplished by building designers when using decorative brickwork, as well as trends in this field. The authors wish to end this article with a recommendation that decorative masonry of different types must continue to be used in constructions worldwide, looking upon them as legacies to be preserved and respected and not lost to the past.

Brick is reusable, recyclable, and cleanable and may be used to build new structures. Old bricks can be reused to create new bricks or, less ideally, to make other construction materials like aggregate or concrete used for landscaping, or as a sub-base for pavements and roads. They can practically always be recycled or used again. Additionally, brick structures may frequently be rehabilitated for new uses due to their longevity and resilience, eliminating the need to create an entirely new construction with all its accompanying environmental effects.

Reusing construction demolition refuse is also becoming a frequent practice to lessen the environmental effect of development as sustainability awareness of buildings' life cycles has increased in recent years. Bricks are the most sustainable construction material available since they are energy-efficient, never need to be replaced, require no upkeep, can be reused and recycled, and minimize the carbon footprint of structures, giving builders the confidence that their work is helping to create a better world.

Author Contributions: Conceptualization, A.A. (Asaad Almssad) and A.A. (Amjad Almusaed); methodology, A.A. (Amjad Almusaed); software, A.A. (Asaad Almssad); validation, A.A. (Amjad Almusaed), A.A. (Asaad Almssad) and R.Z.H., formal analysis, A.A. (Amjad Almusaed); investigation, A.A. (Amjad Almusaed); resources, A.A. (Amjad Almusaed); data curation, A.A. (Asaad Almssad); writing—original draft preparation, A.A. (Amjad Almusaed) writing—review and editing, R.Z.H.; visualization, A.A. (Amjad Almusaed); supervision, A.A. (Asaad Almssad); project administration, A.A. (Asaad Almssad). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the data adopted in this article are from public resources and have been cited with references accordingly.

Conflicts of Interest: The authors declare no conflict of interest. The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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