buildings

Review

Evolution and Current State of Building Materials, Construction Methods, and Building Regulations in the U.K.: Implications for Sustainable Building Practices

Rune Vagtholm [1], Amy Matteo [1], Behrang Vand [1,*] and Laura Tupenaite [2]

[1] School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Edinburgh EH10 5DT, UK; 40504687@live.napier.ac.uk (R.V.); 40208818@live.napier.ac.uk (A.M.)
[2] Department of Construction Management and Real Estate, Faculty of Civil Engineering, Vilnius Gediminas Technical University, Sauletekio al. 11, LT-10223 Vilnius, Lithuania; laura.tupenaite@vilniustech.lt
* Correspondence: b.vand@napier.ac.uk

Abstract: This study presents a comprehensive review of building materials, construction methods, and building regulations on the U.K. mainland. This provides valuable insights into the historical progression and transformation of the construction industry through a comprehensive analysis of both traditional and modern building construction materials and methods and categorising their evolutionary trajectory. Current building regulations in England, Wales, and Scotland are compared, highlighting differences in fire safety, noise safety, energy conservation, and sustainability. For example, fire safety regulations are analysed in detail, including fire resistance duration, wall cladding combustibility, and limitations on unprotected areas. Advances in knowledge and technology have led to increasingly sophisticated and energy-dependent methods, materials, and regulations. This study showcases the vast array of building construction materials spanning centuries, each possessing unique properties and performances. The selected methods and materials represent those currently employed or widely utilised in the U.K. construction industry, affirming their relevance and applicability in modern construction practices. Limitations in construction practices primarily stem from a lack of knowledge and tools rather than material scarcity. Enhancing knowledge and access to advanced tools is crucial to overcoming these limitations and driving advancements in the field. This study provides insights into the evolution of building materials, construction methods, and building regulations that can inform future developments in sustainable building practices. The findings have significant implications for policymakers, building designers, and constructors, particularly in terms of adopting sustainable materials and construction methods that comply with building regulations while reducing the environmental impact of the built environment.

Keywords: building materials; construction methods; building regulations; sustainable buildings; U.K.

Citation: Vagtholm, R.; Matteo, A.; Vand, B.; Tupenaite, L. Evolution and Current State of Building Materials, Construction Methods, and Building Regulations in the U.K.: Implications for Sustainable Building Practices. *Buildings* **2023**, *13*, 1480. https://doi.org/10.3390/buildings13061480

Academic Editor: Audrius Banaitis

Received: 25 April 2023
Revised: 28 May 2023
Accepted: 5 June 2023
Published: 7 June 2023

1. Introduction

The construction of buildings is an ancient and worldwide activity that has been constantly evolving. Archaeological remains of primitive huts by hunter-gatherers have been found dating back to 23,000 cal BP [1]. As a case study, in the United Kingdom (U.K.), various structures from the Neolithic period have shown great durability and remain well preserved [2–4]. The use of flat stone slabs set into mounds of midden provided durability and a degree of thermal insulation in the harsh environment. The roundhouses with walls made of wooden posts, stone or wattle, and daub and covered with a conical thatch or turf roof became common throughout the U.K. from the Bronze Age to the Iron Age [5,6]. These buildings are expected to have been able to withstand a wide variety of climate conditions [7]. During this period, roundhouses unique to Scotland, such as the broch, Atlantic roundhouse, and wheelhouse, also emerged [8]. The U.K. has been influenced by different cultures throughout history that have introduced new technologies. The Roman period from AD 43 to AD 410 brought a range of advanced technologies, such as concrete, ashlar masonry, bricks, and timber framing. The Romans did not hold wattle and daub in high regard due to their potential fire and rot risks [9]. However, the use of mud continued due to its low cost and was not necessarily perceived as a material for peasants [10]. The rectangular shape of the Roman buildings, which allowed for better storage, was another distinct contrast to the roundhouses of the Iron Age [11]. Anglo-Saxon culture placed great value on timber, and prior to the arrival of the Vikings, the majority of secular structures were constructed from this material. Nevertheless, it can be argued that the Viking invasion did not exert as significant an impact on architectural developments as the preceding Roman invasion did [12]. In Scotland, during the 15th century, stone architecture became more commonplace and was adopted in domestic buildings, which saw the traditional rubblestone wall relegated to ashlar masonry [13]. Subsequent to the Middle Ages, architectural styles became so distinct that they were often defined by the period of a monarch's reign. To illustrate, the Tudor era in England was characterised by the opulent use of timber, while the Victorian era was marked by the prevalence of solid brick dwellings [11]. The shift from timber to brick and stone in London's post-Great Fire reconstruction (1666) reflected recognition of the fire risk posed by wooden structures. The resource and labour shortages of the World Wars prompted the exploration of new building materials and techniques to address the housing shortage. Mass-manufactured prefabricated homes emerged in various forms, resulting in quantity being prioritised over quality and deviating from previous eras' skilled craftsmanship. Building science and technology have evolved across eras to satisfy diverse demands, including durability, cost-effectiveness, speed of construction, and even conspicuous displays of wealth [14–16].

The U.K.'s housing shortage persists, and present challenges extend beyond production time, encompassing the imminent threat of global warming. In 2019, residential buildings were responsible for 15% of the U.K.'s total greenhouse gas emissions, primarily resulting from combustion fuels used for heating and cooking. An additional 21% of emissions arose from the energy supply sector, generating enough electricity to meet the U.K.'s total demand [17]. At 33%, domestic demand represents the highest consumption of any sector [18]. In fulfilling its commitment to the Paris Agreement [19] under the United Nations Framework Convention on Climate Change (UNFCCC), the U.K. is poised to take a leadership role exemplified by Scotland, which has set its own indicative National Determined Contribution (NDC) to reduce greenhouse gas emissions by at least 75% before 2030, relative to 1990 levels. This stands in contrast to the U.K.'s current NDC of 68%. Furthermore, Scotland aims to achieve net-zero emissions by 2045, surpassing the U.K.'s 2050 target. These goals demonstrate the significant role that buildings must play in addressing climate change [20,21]. Given the wide range of building technologies and materials available, a degree of control becomes essential. Building regulations have been established to protect occupants according to various targets, including safety, health, and welfare in and around buildings while promoting sustainable development and improving energy conservation [22]. These regulations incorporate British Standards and tools such as the Standard Assessment Procedure (SAP), developed by the British Research Establishment (BRE), which calculates the energy and emissions performance of buildings [23]. SAP 2012 is the latest version used throughout the U.K. The importance of building regulations was underscored by the Grenfell Tower fire disaster in 2017, which the Fire Brigade Union partly attributed to deregulation [24]. Subsequently, the U.K. government commissioned an Independent Review of Building Regulations and Fire Safety in 2018 [25]. The building regulations on fire safety were subsequently tightened across England, Wales, and Scotland to prevent similar cases [26–28]. Local authorities enforce these regulations, while building control bodies, such as a building control department of a local authority or an approved inspector, are responsible for ensuring compliance.

The evolution of building materials and construction methods from the Stone Age to the present day, as of 2021, represents a significant transformation in the field. Innovations such as reinforced concrete, prefabrication techniques, and new structural systems emerged during this time, revolutionising the way buildings were designed and constructed. These advancements not only improved the efficiency and durability of structures but also laid the foundation for subsequent developments in the field. However, it is crucial to note that the advancements of the post-war era did not render previous building techniques obsolete. Instead, the industry embraced a blend of traditional and modern methods to address various construction challenges. This hybrid approach acknowledges the strengths of both historical techniques and contemporary innovations, resulting in buildings that combine historical charm with modern functionality and sustainability. The literature currently available on the review of building materials and construction methods is limited, with scant attention paid to their potential to comply with building regulations. Furthermore, no existing publication provides an in-depth analysis of these factors. This study comprehensively reviews building materials and construction methods from centuries ago, evaluating their compliance with building regulations spanning several decades up until 2021. By exploring the historical evolution and regulatory alignment of these materials and methods, it addresses the knowledge gap on the U.K. mainland and provides valuable insights for informed decision making in the construction industry. To achieve this, this study conducts a literature review looking at the history of building materials and available methods of construction, covered in Section 2. Section 3 compares and highlights the differences between current building regulations in England, Wales, and Scotland to apply the review to a wider area.

2. Methods of Construction

The methodology employed in this research adopts a systematic approach to comprehensively explore the capacities of building materials and construction methods, with a particular focus on their efficacy in meeting regulatory standards in 2021. The study initiates by providing a meticulous overview of building materials, tracing their historical significance from the Stone Age to the present era. Subsequently, it delves into a profound investigation of various construction methods, encompassing both traditional techniques that have stood the test of time and modern innovations that align with technological advancements and societal requirements. In addition to the materials and methods, the research also examines the regulatory framework governing building construction. This examination illuminates the intricate interplay between materials, construction methods, and regulatory requirements. By amalgamating historical insights, contemporary practices, and regulatory considerations, this article establishes a comprehensive knowledge base that empowers informed decision making, fosters sustainable building practices, and advances the fields of construction and architecture.

In order to provide a comprehensive overview encompassing both traditional and modern methods, a thoughtful selection process was employed to determine the inclusion of MoC and materials in this study. The selection criteria were carefully established based on multiple factors, including historical significance, availability, and relevance to the current building regulations in the U.K. Regarding historical significance, MoC and materials were chosen to represent key milestones and significant shifts in construction practices throughout different periods. This allowed for the examination of the evolution of building techniques and the impact of advancements in knowledge and technology on construction methods over time. The availability of the MoC and materials was another crucial consideration. The selected methods and materials were chosen to represent those that are currently in use or have been widely employed in the U.K. construction industry. By focusing on available options, the study aimed to provide insights that are directly applicable to practitioners and decision makers in the field. Furthermore, the relevance of the MoC and materials to the current building regulations in the U.K. played a pivotal role in their selection. The chosen methods and materials were evaluated based on their alignment with the regulatory frameworks governing construction practices. This consideration ensured that the study's findings would reflect the current compliance requirements and provide guidance on their applicability within the regulatory context. By incorporating these selection criteria, this study presents a comprehensive and representative overview of MoC and materials, encompassing their historical significance, practical availability, and adherence to current building regulations in the U.K.

In 2018, the housing stock in the U.K. was estimated to consist of nearly 29 million homes. The majority, at 84%, of these homes were in England, while homes in Scotland and Wales only represented 9% and 5%, respectively [29]. Throughout history, a diverse array of construction methods have been utilised to construct homes, many of which remain in use today. In the subsequent sections, an exhaustive classification of these techniques is presented, delineating the distinct realms of traditional and modern methods of construction. This comprehensive exposition highlights the remarkable journey of evolution, tracing the utilisation of humble mud as a building material to the pinnacle of contemporary off-site construction, where fully prefabricated three-dimensional homes are brought to fruition.

2.1. Traditional Methods

Traditional construction methods are often characterised by manual and labour-intensive approaches that were predominantly employed prior to the 20th Century, coinciding with the advent of novel techniques and materials. These methods embody a linear progression inherited from historical practices, where each stage of the construction process is sequentially completed on-site before advancing to the next phase. It is worth noting that a considerable portion of the U.K.'s existing housing stock, comprising approximately 5.9 million units, was erected prior to 1919 [30], thereby falling within the realm of traditional construction. Despite the prevalence of modern construction methods, traditional approaches continue to hold significant relevance in contemporary construction practices. Notably, the traditional cavity masonry wall accounts for nearly 75% of newly constructed buildings [31]. Consequently, the classification of traditional construction methods is often contingent upon the specific materials utilised in their implementation.

2.1.1. Ancient, Durable and Natural Construction Materials: Rammed Earth and Cob

The concept of "natural construction" encompasses a wide range of construction methods that harness the inherent qualities of earth, timber, and stone, among other natural materials. These materials have served as foundational elements in early construction practices and continue to be in high demand today. Natural construction is characterised by the utilisation of earth, timber, and stone, along with other natural materials, which have a rich historical lineage tracing back to the earliest forms of construction. It is noteworthy that even in the present day, approximately one-third of the global population resides in dwellings made of unbaked earth, highlighting the enduring relevance and preference for natural materials in modern construction. This emphasises the sustained demand for natural materials and their continued significance in shaping sustainable and environmentally friendly construction methods [32].

Rammed Earth

Throughout history, rammed earth (RE) has been a venerable construction material that has been adopted worldwide. Its development can be traced back thousands of years to northern China, and it was also present in the Phoenician settlements in the Mediterranean. However, its use has been limited in the U.K. despite its strength and durability [33].

RE, shown in Figure 1, is composed of a mixture of different types of aggregates, such as gravel and clay, which are rammed into temporary formworks usually made from timber to create walls. The difference in the soils has resulted in a lack of research and provisions regarding a uniform way of approaching this method of construction. As a result, when this method was first introduced, all RE constructions relied on the rule-of-thumb method. This introduced uncertainty into the building, which is a particular safety concern when the building is subject to increased dead, live, or environmental loads [34]. However, unlike early timber structures, the non-combustible earthen walls provided higher fire safety.

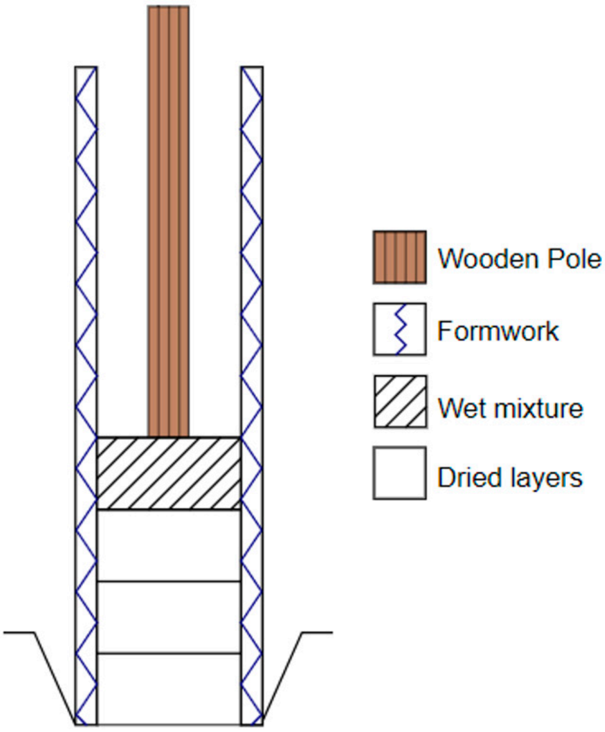

Figure 1. Rammed earth wall process.

When gathering the materials, the earth is sourced from either the site itself or surrounding areas. Traditionally, the moist mixture is rammed and compacted into the formworks using a wooden pole, typically in layers of around 100–150 mm × 300–450 mm thick. The compressive strength of the wall is linked to its moisture content and should be given an extended period to dry [35]. With proper drying and moisture control, it is possible to achieve a higher compressive strength [36]. Once the mixtures have been compacted and cured, the temporary formworks are removed to reveal monolithic walls.

In the U.K., RE has only seen limited use, typically in one or two-story high load-bearing wall construction. It is important to note that RE falls into two subcategories based on the binder used: stabilised and unstabilised. Stabilised RE, which will be discussed further in this section, is the more modern material of the two. The physical properties of the mixture can be enhanced by incorporating lime or cement as binders, thus improving its overall durability. Conversely, unstabilised RE employs only clay as the binder, and although it still offers a good degree of durability, it is more susceptible to environmental erosion [37].

Cob

Earthen homes in the U.K. are predominately represented by cob houses [38]. Like RE, cob is another ancient and durable method of construction, consisting of combining clay subsoil, water, sand, and straw, as shown in Figure 2.

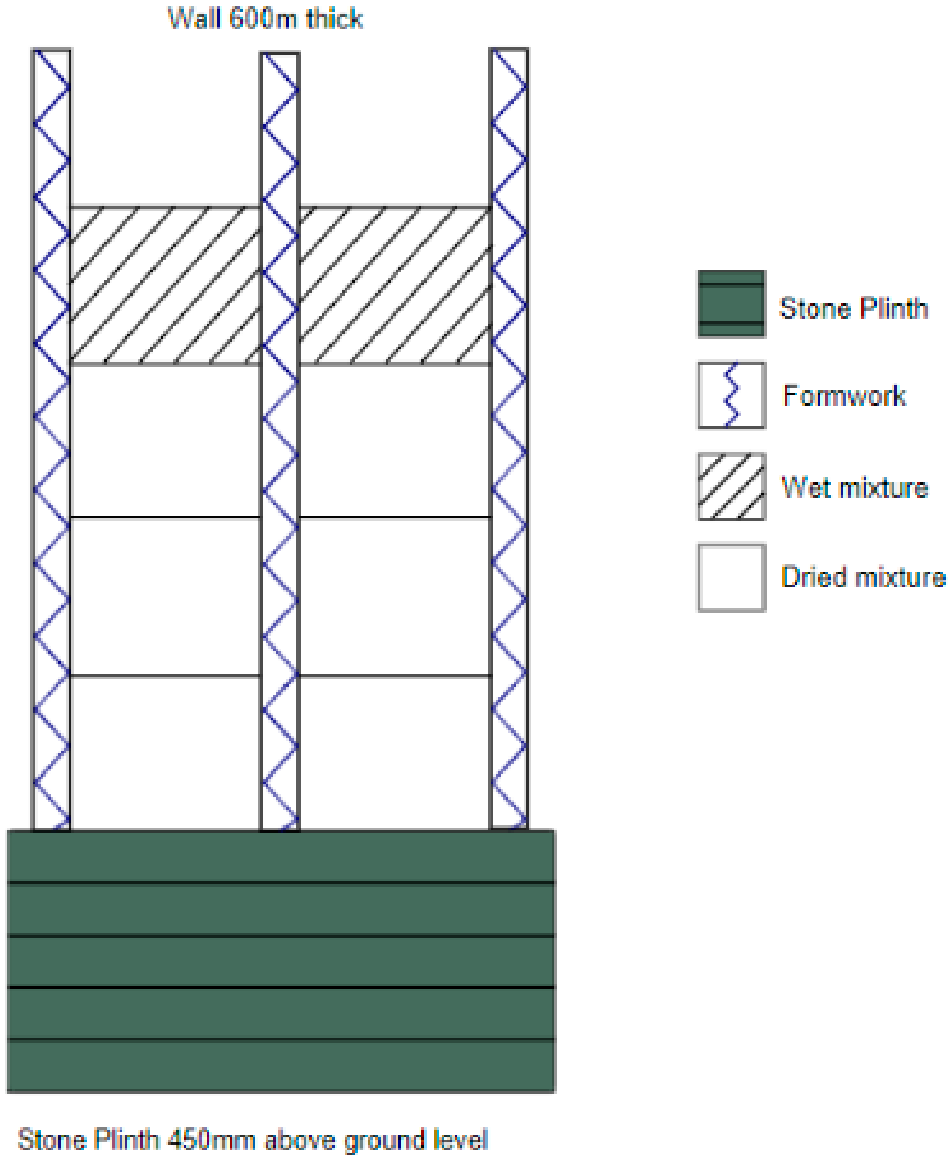

Figure 2. Cob wall process.

With some cob structures date back to the 13th century, the U.K. first became acquainted with the material around the 15th century. It remained common in counties such as Devon and Cornwall until the fired clay brick was industrialised in the 19th century.

A cohesive mixture was obtained by distributing and layering the materials evenly and then trampling on the mixture by foot [39]. The rammed earth construction method is highly dependent on the amount of water used in the mixture. Excessive amounts of water make the mixture too soft and difficult to use, requiring several days of drying time. Conversely, inadequate water makes the mixture challenging to compact and prone to crumbling. After the mixing process, the material is compacted to create building walls, with a typical thickness of around 600 mm [40]. This thickness is largely responsible for the strength of the structure, as the compressive strength of the cob is relatively low [41]. Typically, cob walls are built off stone plinths, varying from 450 mm above ground level to the first floor in domestic buildings.

Cob, as a building material, has certain thermal properties that may make it less attractive in certain climates. Despite its thickness, cob walls are poor insulators and the degree of thermal insulation is dependent upon the moisture content and density of the walls. However, cob walls provide a high thermal mass which enables them to store thermal energy [42]. This feature can be beneficial in warmer climates, as it allows heat from the sun to gradually be released in the cooler evenings. However, in cooler climates, this thermal mass can hinder heating a dwelling with intermittent heating [43].

Despite the addition of combustible straw, the thickness of cob walls is expected to provide a decent amount of fire resistance, although limited testing has been carried out in this area. The amount of straw used in cob dwellings typically varies between 1.5% and 2%. However, the integrity of the walls during a fire is reliant upon regular maintenance, as cracks resulting from shrinkage can enable fire to penetrate the wall [44].

2.1.2. Sustainable Construction with Wood, Straw Bale, and Cordwood

The use of wood is one of the earliest methods of construction that has survived through the decades. Wood was usually used shortly after being chopped down, so it was unseasoned and therefore considerably easier to work with compared to seasoned wood. The utilisation of timber in construction has not been without challenges. One such challenge is the fact that timber tends to shrink as moisture evaporates from it. To mitigate this, air or kiln drying has become a common practice to control the moisture content of the timber.

Timber supply has been through difficult periods. Woodland areas in the U.K. have seen a notable recovery since their depletion caused by the wars in the early 20th century. Woodland coverage has risen from 4.7% in 1905 to over 13% in 2019, with conifers accounting for 51% of the total woodland area [45]. Despite the strong presence of softwood, only 33% of the sawn softwood in 2018 was used in construction [45]. Due to early harvesting, the strength of timber has reduced, making it unsuitable for construction, resulting in the need for imported timber. Sweden has been the principal country for importing timber to the U.K., accounting for 41% of all imported sawn softwood in 2018 [45,46].

Straw Bale

Straw, as illustrated in Figure 3, is an agricultural fibre made from growing crops such as rice, wheat, and oats, and under the right conditions can last for hundreds of years [47]. However, just like all other natural fibres, under typical conditions, the straw eventually deteriorates. The survivability of straw bale construction is strongly influenced by two key factors: temperature and moisture content [48]. With the development of steam-powered balers and stationary horses, leftover straws from harvests can be compacted into bales, making this an exceptionally sustainable construction method [49]. Furthermore, compared to other construction methods, straw bale construction requires considerably lower levels of human resources and skills [50].

Depending on the type of straw used in construction, there may be varying results, similar to RE construction. Rice-straw bales, for instance, did not align in the same direction as previous bales, leading to the development of rods and pins for structural purposes [51]. The performance of straw can also be affected by whether it is halophytic (salt-tolerant) or not, as it is hygroscopic and requires specific attention when rendering. The load-bearing walls are constructed by stacking straw bales in rows on a raised plinth, usually within a timber frame, and then plastering with earth render. A basic roof can be constructed using a timber skeleton to protect the bales from weathering damage. Exposing the straw defeats the purpose of any roof covering, while the render provides a degree of fire resistance. The compressed bales are much less of a fire risk than loose straw on site. Like wood, the charring of the outer layer during a fire further slows the decomposition and helps protect the structural integrity [52]. Pest infestations are not usually an issue and do not affect the durability of the structure, but the moisture content can have a direct impact on longevity. Any moisture content over 25% for an extended period can lead to wall deterioration, while continuous wet and dry cycles are manageable as long as the structure can breathe. However, this raises questions about the method's suitability in areas with high humidity [53].

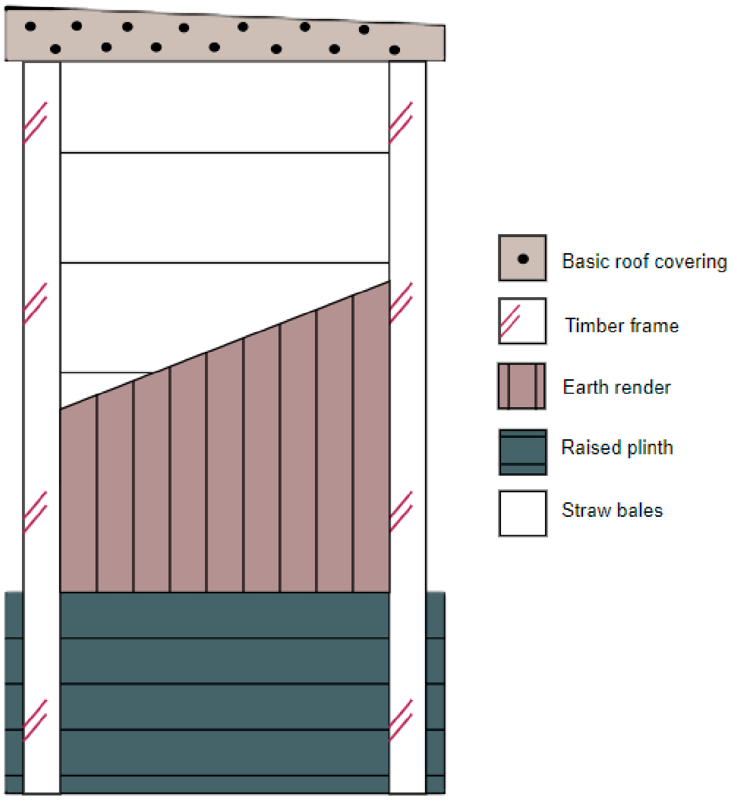

Figure 3. Straw bale wall process.

Cordwood

Cordwood construction, as shown in Figure 4, is an ancient building method that has been in use for nearly two centuries [54], and the origin of the first cordwood log structure remains unclear [55]. In the early 19th century, cordwood gained popularity in Europe and North America. Despite its longevity, this method has never been standardised into a definitive practice like other construction technologies, as it has attracted a multitude of innovative individuals with unique ideas. When cordwood is plastered, these dwellings will appear like standard structures; however, when the wood is exposed, it creates expressive and eye-catching designs.

Constructing a cordwood dwelling requires no more skill or human resources than straw bale construction. No expensive equipment is necessary; however, it can be time-consuming. To begin, the log ends need to be prepared, which involves cutting, debarking, and drying them [56]. Once the mortar is ready, the first layer of the prepared wood can be placed on a bed of wet mortar, and so on and so forth. Cordwood construction, a popular building method for over 200 years, combines various construction techniques in different variations. Although it could be classified as masonry due to the use of mortar, cordwood buildings use log ends in place of bricks, requiring careful selection of the right type of wood and positioning of the log ends with their fibres at the correct angles to maximise overall strength [54]. Selective use of durable and rot-resistant wood helps extend the longevity of the construction. Mud-soaked cloths, a common practice in Scandinavia, can be used to tighten the walls for additional structure.

The thermal performance of cordwood is low compared to most other methods and the best performance is achieved at the log ends. This performance can be worsened by the structure's susceptibility to moisture. As the moisture content in the wood drops below 30%, the wood starts to shrink, which can lead to gaps between the wood and the mortar. This issue even persists when the wood is kiln dried to control the moisture content, as the wood absorbs the moisture from the mortar during the construction phase.

Failure to account for shrinkage can have significant impacts on a building's thermal performance, structural integrity, and fire safety [57].

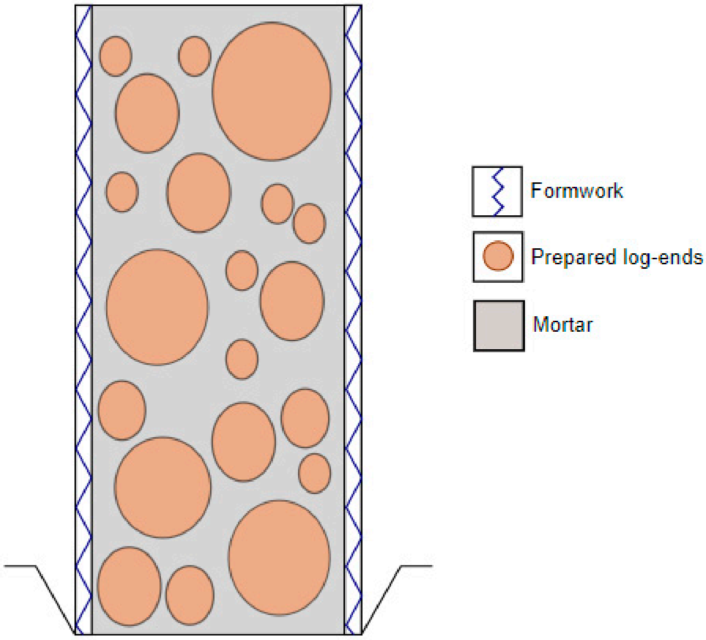

Figure 4. Cordwood wall process.

2.1.3. Masonry

Masonry construction has been a traditional approach to separate internal and external spaces using single-leaf walls for several decades. This technique involves assembling blocks to create a robust structure held together by mortar, which was widely adopted until the mid-twentieth century [58]. The strength of the blocks used and the quality of the mortar are essential factors in ensuring the structural stability of masonry dwellings. Masonry construction can be used to produce both load-bearing and non-load bearing structures [59].

Adobe

Adobe translates to "mudbrick" and is among the earliest building materials known to man. Similar to RE and cob buildings, this method of construction, presented in Figure 5, consists of natural materials, such as natural fibres, water, and soil, which are mixed and left to dry. The water is essential for the workability of the mixture. The clay content of the soil serves as the main binder and, ideally, the portion makes up 12–16% of the composition. The clay is also responsible for the absorption of moisture and shrinkage during the drying phase, which can have adverse effects if not controlled [60]. Natural fibres such as straw are used to control the moisture content of the mixture, which helps prevent uneven drying and cracking [61]. These fibres also help improve the thermal performance of the bricks, as their thermal conductivity is considerably lower than the other components [62].

Adobe bricks, traditionally produced in the summer months, are created by combining clay soil with straw or other fibrous materials [63]. The mixture is then placed into timber-cast moulds and left to naturally dry out in the sun. After the drying stage, the adobe bricks can be layered on top of each other using an earthen mortar. To ensure stability is maintained, buttresses are often installed throughout many adobe structures. In the past, earthen mortars were the only option available. Once the dwelling is completed, a final coat of render is applied to protect it from weathering effects. The durability of the bricks is testified to by the fact that these buildings have lasted hundreds of years. This is dependent upon the maintenance and environment they are located in. Rain erosion is the main risk, and extended periods of rain can jeopardise the integrity of the walls [64].

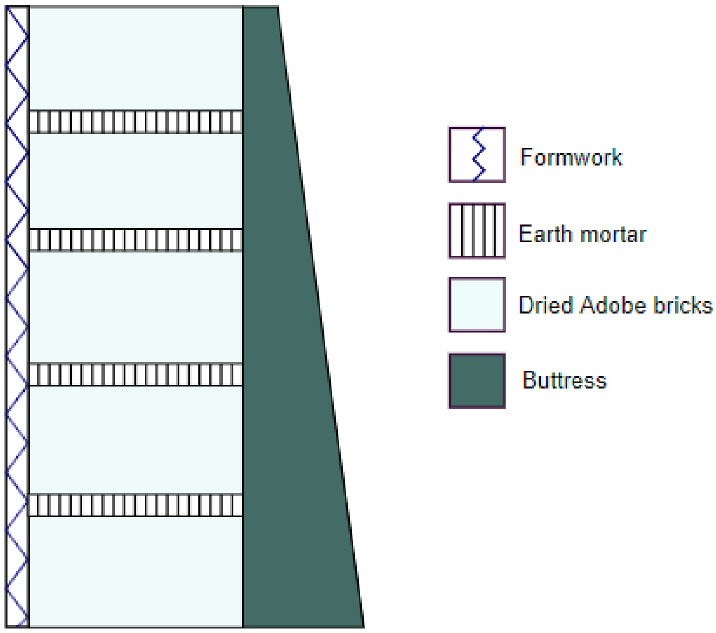

Figure 5. Adobe wall process.

The opportunist in situ gathering of raw earth materials meant the mechanical properties of the bricks varied. The large benefit was the reduced material and transport costs. As for today, the cost-efficiency remains but the lack of standardisation is a hurdle in terms of meeting regulations [65].

Clay Brick

Fired clay brick can be traced as far back as 5000–5300 years ago in China [66]. Fired bricks were widely used in ancient Greece from around the 4th century due to the abundance of limestone [67]. During the Roman period, fired clay bricks became popular under the Empire as kilns allowed for faster manufacturing. The bricks were often set in highly hydraulic Roman cement [68] or stacked using a brick bond. The manufacturing of fired clay bricks has many similarities with adobe bricks. The selection of raw materials for the bricks such as white and red clay was essential to improve durability [9]. The extracted clay was moved to storage, where it was rummaged to reduce the soluble salt concentration producing a more homogenous material. It was then further crushed and mixed with water to increase the plasticity needed for the moulding process. The plasticity could further be controlled by adding sand to avoid excessive shrinkage during the drying phase [69]. The process of creating durable bricks was a crucial development in ancient building practices. After being removed from the mould, the wet mixture would begin the drying phase, and the bricks were placed in open shelters. However, this phase was susceptible to weather conditions, and to ensure uniform drying, it would typically start in the spring or autumn when temperatures were more moderate. The Romans recognised that after the initial drying phase, the bricks would require further sun-drying for a minimum of two years to increase their resistance before they could be deemed suitable for use in construction. This extended sun-drying phase was essential to enhance the brick's strength and durability, which were crucial factors in the construction of long-lasting structures [9]. The use of kilns reduced this phase and bricks were burned at degrees up to 900 °C. This firing process considerably improved both the mechanical strength and durability of the bricks compared to the previously used mud bricks. These bricks lacked uniformity as they were handmade and usually varied in the range 300–400 × 400–500 × 25–60 mm [67]. Similarly, the colouration of the bricks would vary depending on the placement in the kiln, firing time, and raw materials [70]. However, the colour variation is mainly caused by the concentration of metallic oxides in the clay, such as the red tone produced by iron oxide [71].

Today, fired clay bricks are commonly manufactured using machines, as shown in Figure 6. The manufacturing process has been improved with the use of vacuum chambers to remove air from the extracted clay. Instead of open shelters, modern dryers provide full control over the environment during the drying phase [72]. Kiln technology has also advanced, enabling bricks to be fired at higher temperatures, resulting in increased mechanical strength [73]. The current standard brick dimension is 215 × 102.5 × 65 mm [74], and a range of products with different compression strengths and durability is available on the market to cater for various needs [75].

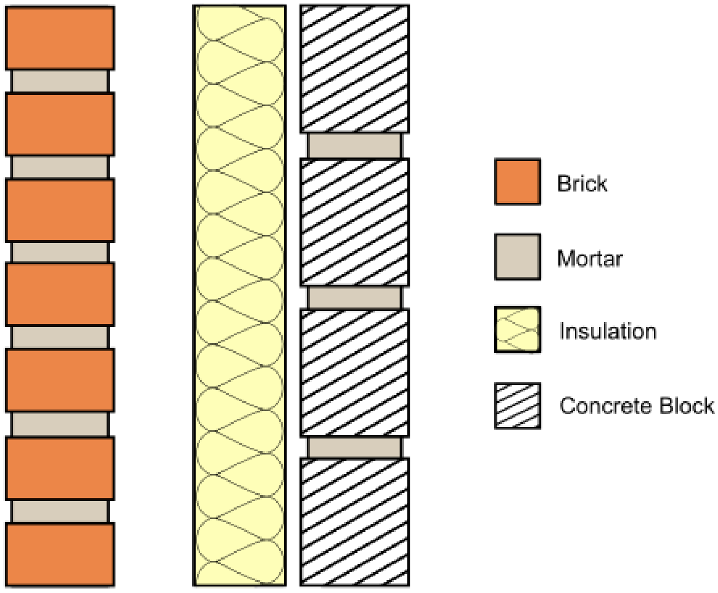

Figure 6. Brick block cavity wall.

In today's construction, brick, and block construction is the most common type of construction in the U.K., accounting for 75% of new buildings [31]. In this method, clay bricks are used in the non-load-bearing outer leaf of cavity walls to protect against weather conditions, as shown in Figure 6. However, these bricks are not completely impervious to the elements, and prolonged exposure to wind-driven rain can lead to moisture entering the cavity [76]. To regulate this moisture, weep holes are incorporated into the outer leaf to ventilate the cavity and facilitate moisture escape. The load-bearing inner leaf is often built from brick or block, but timber framing is gradually replacing it [77]. The outer and inner leaves are separated by a 100–150 mm wide cavity and joined by cavity wall ties to maintain the stability of the outer leaf. To enhance thermal performance, insulation is placed in the cavity, except in the case of timber framing, where insulation is added as infills in the frame [78]. While bricks are known for their good fire resistance, a lack of cavity barriers can allow a fire to spread rapidly within the cavity [79]. The use of Roman cement declined in the first half of the 20th century with the emergence of Portland cement mortars [68].

Hempcrete

Hempcrete, a bio-composite material consisting of hemp, water, and lime, has been used for thousands of years and was first developed in France. Hemp is a fibre extracted from the stem of a cannabis Sativa plant with a high silica content known as "shives". This hygroscopic fibre can absorb up to five times its own weight in water, allowing the mixture to contribute to regulating the humidity of the dwellings while simultaneously absorbing CO_2 from the atmosphere, giving it a negative carbon footprint. The mixture creates a natural lightweight concrete that can be used for construction and insulation, with the thermal properties of the hemp fibres and their density enabling it to be both load-bearing and provide insulation. Hempcrete is presented in Figure 7. However, the mixing process and slow drying phase mean that construction time can take up to several months [80,81].

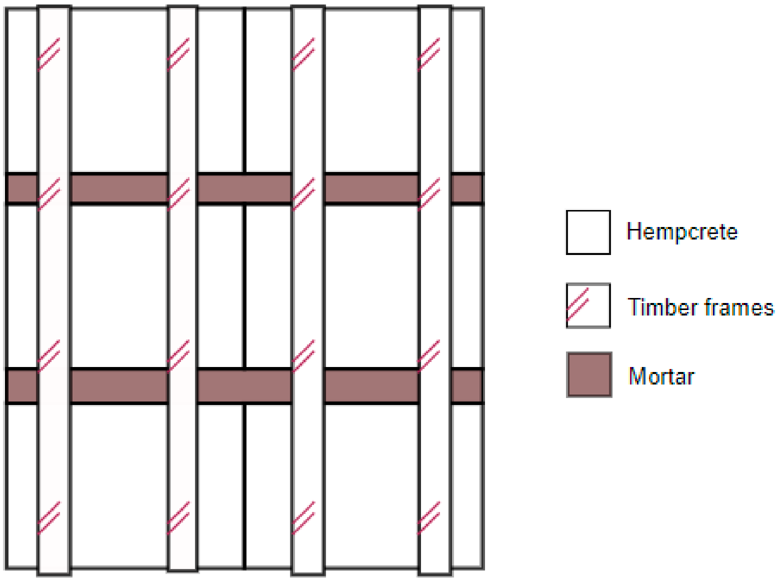

Figure 7. Hempcrete wall process.

The hempcrete blocks are easily stacked on top of each other separated by mortar, as they weigh only one-seventh of concrete. During construction, the blocks should be protected from any rising water; therefore, they should be designed with enough space at the base of the wall for water to run off [82]. The blocks can easily stand alone as they are self-supporting; however, timber frames are commonly used.

Hempcrete does have some large drawbacks, particularly regarding its mechanical properties, which limit its use. Its compressive strength is considerably lower than other masonry materials, which makes it less favourable for vertical construction [83]. Moreover, the material is not suitable for all locations, as the moisture content in the hygroscopic fibres increases the thermal conductivity of the blocks [84].

Sandstone

Sandstone has a significant historical presence in the U.K., particularly in Scotland, due to geological factors. The use of stone buildings in Scotland dates back to 4000 BC when farming created a need for more permanent structures. The construction process of these buildings was labour-intensive, and the sandstone was typically sourced from local quarries to overcome transportation challenges.

Ashlar masonry, which was introduced by the Romans in the 1st and 3rd centuries AD, became commonplace on the facing facades of domestic buildings in the mid-17th century. Prior to this, various stones, including sandstone, were used to construct rough rubble walls. Despite the new popularity of ashlar masonry, rubble walls were not abandoned and instead served as internal walls [85].

Sandstone is a sedimentary rock that consists of varying sizes of quartz grains and is usually naturally cemented by silica or carbonate. The stones can differ significantly in terms of structure and appearance. The porosity of sandstone ranges from 0 to 35%, but typically falls between 15 and 20%, which is relatively high compared to other rock types. The colour of the stone varies from red, orange, and yellow, depending on the presence of oxides, and weathering can further affect its appearance [86]. Sandstone is a durable material when properly maintained and kept in appropriate conditions. However, its high porosity makes it susceptible to decay caused by crystallization. Moisture movement in the stone is normal, but trapped moisture during freeze-thaw cycles can lead to crystallization, which may significantly damage the stone. Coastal areas can also pose a problem, with the salt ratio in droplets causing crystallisation decay inside the pores and salt efflorescence on the surface. In urban areas, the presence of microorganisms or atmospheric pollutants can accelerate the deterioration rate of the stone. As such, sandstone may have better long-term prospects in rural areas than in modern cities [87,88].

Sandstone is a natural material commonly used in historic buildings due to its strength, durability, and non-combustibility. Unlike other natural materials, sandstone can withstand high compressive loads but its compressive strength varies greatly and is dependent on porosity [89,90]. Although sandstone has a high thermal mass, it provides little insulation, so the walls are often very thick to compensate. However, the thickness of the walls means that the buildings have a slow response time to temperature changes [91].

2.2. New Methods

The evolution of modern and non-conventional methods of construction can be attributed to the transformative changes that occurred in the construction industry following World War II. At that time, the population faced significant challenges, such as housing shortages, scarcity of skilled labour, and limited resources. Consequently, there was a strong impetus among construction professionals to embrace innovative technologies that could enhance production efficiency and reduce resource consumption [92]. Furthermore, there was a shift in focus towards improving living standards and energy performance in the built environment. In response to the post-World War II housing shortage, the U.K. witnessed a substantial surge in the annual completion of new homes, reaching its peak in the late 1960s at 350,000 units before gradually declining and stabilising at around 150,000 units [93]. Throughout this period, masonry construction continued to play a prominent role in modern construction, with the adoption of various new techniques. Additionally, advancements in off-site panelised and volumetric construction methodologies have contributed to the diversification of construction practices. However, amidst these developments, the utilisation of natural construction materials has gradually waned in favour of industrial materials and techniques, due to the need to accommodate the increasing demand for housing and overcome resource limitations. Nonetheless, it is important to recognise that the rich knowledge and experience acquired over centuries of using diverse materials in construction continue to inform the design of new construction methods and shape the contemporary built environment.

2.2.1. Masonry

As previously mentioned, masonry construction is an ancient method that has adapted to technology and the construction industry over the years. Concrete has become the second-most consumed building material in the world, second only to water [94]. The use of cavity walls became popular in the early 20th century and is still the most commonly used method for new builds in the U.K. [77]. These cavity leaves are predominately constructed using brick and block [95].

Stabilised Rammed Earth

RE construction is one of the earliest known methods of construction. In recent years, RE dwellings have gained attention due to their sustainability benefits. The use of natural materials that require little processing and can be recycled, as well as being sourced on site to reduce transportation and costs, make this low-carbon approach particularly attractive [96]. However, the inconsistency in soil mixtures and the lack of safety measurements in the traditional "rule-of-thumb" approach necessitated changes to bring this ancient construction method up to modern standards. Despite these changes, the foundation of RE construction remains the soil mixture, typically consisting of gravel and clay, which has numerous positive attributes. To meet structural building criteria, stabilisation is required. This is achieved by manually compacting the mixture and adding a chemical additive to improve its properties. Common additives include lime (lime-stabilised rammed earth) and cement (cement-stabilised rammed earth) [97].

The thick walls (200–450 mm) of traditional RE dwellings provide thermal insulation and structural stability to withstand location-based loads such as snow and wind. However, stabilisers are often added to the soil mixture to improve structural strength and reduce material usage. The increased strength from cement stabilisers makes it possible to reduce the width of walls, although a minimum wall thickness of 250–300 mm for a one- or two-story building is still recommended [98]. Despite the increased durability provided by stabilisers, challenges remain in meeting modern expectations for the durability of external walls when exposed to moisture [99,100]. Additionally, traditional RE and stabilised RE have poor thermal insulation properties. The density and thermal conductivity of the mixture are further increased by the addition of cement and lime stabilisers. While there is a large variation in thermal performance measurements, stabilised RE generally performs better than concrete [101–103]. However, cement stabilisers perform worse than their lime counterparts [104].

Precast Concrete

The modern prefabricated precast concrete (PC) system was first developed in 1905, but it was not until the 1960s that standardised off-site panels were adopted for both low- and high-rise buildings. However, a lack of understanding at the time led to problems such as corrosion of internal steel reinforcement, adverse effects from additives, and disproportionate collapses. Despite these issues, the construction industry continued to develop this technique to meet modern standards [92]. The materials used for PC are the same as those used for cast-in-situ concrete (CIS), consisting of water, cement, and coarse and fine aggregates, with Portland cement serving as the main binder in today's construction. The ratio of these materials, along with steel reinforcement, is adjusted based on the desired output. The mixture is poured into reusable moulds in a factory environment, which is the main difference from CIS. Reinforcement is commonly used for PC panels used in high-rise buildings to address concrete's weak tensile strength, and this can be further increased through prestressing by tensioning the reinforcement before or after the concrete has been set [94].

The controlled off-site factory environment gives PC advantages over CIS, which increase production speed, quality, strength, and durability. The avoidance of weather changes allows the concrete to cure at the desired rates to optimise strength and durability. Concrete strength is tested in accordance with BS EN 12390-1 [105] and classified between C8/10 and C100/115 in BS EN 206-1 [106] (complemented by BS 8500-1 [107] in the U.K.) based on the minimum cylinder and cube compressive strengths. The use of PCs in construction provides several benefits. Furthermore, the precision achieved in the factory increases the durability of the steel reinforcement by placing it optimally to limit corrosion [108].

On site, PC overcomes construction restrictions due to curing duration and strength. The highest strength gain occurs during the first week, but it takes longer to meet the actual design strength [109]. Despite these benefits, off-site manufacturing poses some challenges. For example, PC panels typically weigh around 500 kg and require transportation and on-site installation, during which they are vulnerable. Concrete is a complex material to predict with regard to its thermal behaviour, as multiple factors affect it. Among various building materials, concrete has a relatively high thermal conductivity. Thermal conductivity is mainly influenced by the choice of aggregates; however, other factors such as age, moisture content, and temperature also play a role. The poor thermal performance of concrete has led to the development of precast concrete sandwich panels, which consist of an insulation layer sandwiched between two layers of concrete. These panels take advantage of the strength and durability of concrete while improving its thermal performance [110]. Concrete has become a widely used building material due to its versatility, strength, durability, and non-combustible properties. Despite early issues with PC panels, the construction industry did not lose faith in this technique, and it has evolved to address concerns and meet modern standards. However, the high consumption of concrete and the cement industry's significant contribution to global CO_2 emissions have raised sustainability concerns. To address this issue, the precast industry has been reducing CO_2 emissions through the replacement of cement, recycling of materials, and the use of renewable energy sources. Although concrete's popularity remains high, its sustainability concerns highlight the need for continued development and improvement in the industry [111,112].

Hybrid Concrete

Hybrid concrete construction combines both PC and CIS components to take advantage of their qualities. The strength, durability, and quality advantages of PC were mentioned in the previous section but there are scenarios where CIS becomes the better choice. The factory environment is ideal for the manufacturing of repetitive elements such as beams and panels, but it is an uneconomic approach for bespoke areas and tying panel frames together. CIS exhibits higher design flexibility in the later stages, unlike PC, which requires an early commitment to the final design. The major benefit of combining the two techniques, aside from cost, is the relatively simple buildability. It allows PC components to be manufactured beforehand, stored off-site, and lifted directly into place from the delivery lorry when needed [113]. Executed correctly, this can lead to both an overall reduction in time and cost as opposed to using CIS on its own or even steel framing [114].

Tunnel Form

The concept of tunnel-form emerged in the early 1950s as a proposed solution to tackling the post-war housing crisis [115]. It is particularly suited for repetitive construction, such as that found in student flats, hotels, or residential blocks.

Unlike traditional CIS the reuse of off-site prefabricated formwork more closely resembles the precasting processes found in a factory. The reuse of these forms increases the speed, quality, and accuracy compared to CIS while taking advantage of the flexibility of CIS [116]. The use of L-shaped formwork (shown in Figure 8) allows for the creation of an inverted U-shape, which can be used to cast floors, ceilings, and walls. This approach offers flexibility and adaptability in terms of design throughout the project. While the rooms are initially arranged to be identical, the large alcoves and infill panels enable alterations to be made to the design if desired.

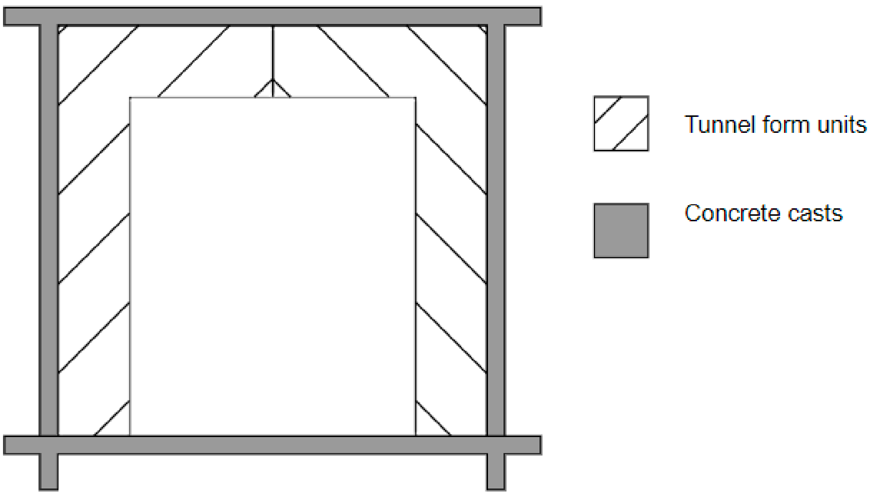

Figure 8. Tunnel form wall process.

Tunnel-form construction has gained popularity due to its efficient and cost-effective method for high-rise buildings. After assembling the L-shaped units and reinforcing them, the concrete is cast in a single operation to form a monolithic structure, which minimises cold joints and assembly time. This construction method results in thinner walls compared to reinforced PC panels, reducing material costs. The corridors and doorways are boxed off before casting to seal any tunnel ends, enhancing the structure's robustness and durability [117].

Flat Slabs

Flat slab construction originated in the United States in the early 20th century [118]. This technique uses large pieces of reinforced concrete slabs, with the weight distributed across concrete columns, eliminating the need for beams or girders. These are constructed as two-way slabs, with the load transferred in both directions. The absence of the girders offers considerable design flexibility and makes it possible to lower the floor-to-floor distance, which generally results in a reduced building height and cost. The flat ceiling surface is particularly useful in terms of services, as the requirement for diversions of structural elements is reduced [119]. As structural members such as columns and mesh can be prefabricated off-site, they share the benefits gained from the controlled factory environment. Similar to hybrid concrete, the in situ casting of the slab combined with precasting increases the buildability.

T-beam concrete slabs are commonly used in construction due to their ability to span long distances with relatively thin construction. These slabs are typically constructed with a thickness ranging from 250 to 350 mm, but their largest weakness is the risk of punching shear failures at the support columns where the load concentrates. To address this issue, drop panels can be utilised between the columns and the slab to reduce the risk of failure. However, the use of drop panels reduces the floor-to-floor height benefit. Alternatively, the thickness of the slab can be increased to improve its strength and ability to withstand the forces at the columns. Another option is the use of fibre-reinforced polymers that can be glued to the concrete surface to increase the flexural stiffness and strength of the slab. However, this approach may lead to a more brittle material with reduced deformation capacity [120–122].

2.2.2. Wood

Wood has a long history in construction and remains popular today, especially in off-site panelised construction. It is preferred over steel for low-rise buildings due to its versatility, low embodied energy, and renewable nature [123].

Timber Frame

The use of off-site panelised systems in construction has a long history in the U.K., dating back to the 1950s and 1960s, with timber being the primary material used for framing. Some manufacturers also experimented with aluminium and steel. However, in the 1980s, timber framing lost popularity in England due to concerns over its susceptibility to rot. Scotland, which has a long tradition of using timber and stone in construction, was less affected by these concerns. Despite significant improvements in quality compared to post-war construction, there is still some reluctance to adopt timber framing in England and Wales. In 2016, 83% of new homes in Scotland were constructed using timber framing, while only 23% of new homes in England and 31% in Wales used this method [123,124].

Timber panels used in panelised construction can be categorised as closed or open panels based on their state when they leave the factory. Open timber panels are constructed from timber studs in a factory environment to ensure accuracy, speed, and quality. On-site, the individual panels are assembled and then fitted with insulating layers, sheathing boards, and services. The timber panels provide the load-bearing element, while the outer skin, made from materials such as brick or stone, offers weather protection. An air cavity and waterproof breather membrane are placed between the outer skin and the timber panel to manage moisture. Fire-resistant and vapour-control layers are typically added internally. Closed timber panels, on the other hand, are an adaptation of open panels and may already have insulation, external finishes, services, or even cladding. This approach provides a high degree of flexibility to meet different design requirements. As all of these activities occur in the factory, it is possible to leverage the benefits of the factory environment at every stage [125].

These methods of construction become increasingly popular as construction companies increase their output to address the housing shortage while being expected to lower their carbon footprint at the same time. The flexibility and lower processing requirement of timber compared to other materials used in modern method construction give it a high potential. However, the unwillingness to adopt new techniques and leave the traditional ones behind remains a barrier. In 2016, companies that adopted modern methods of construction still mainly preferred to use open timber frame panels and to complete the rest of the work on site [126].

Structural Insulated Panels

In the 1930s, a new type of closed panel emerged that was considerably different from timber frames. These were structural insulated panels (SIPs), as shown in Figure 9, which were constructed from paperboards sandwiched between plywood.

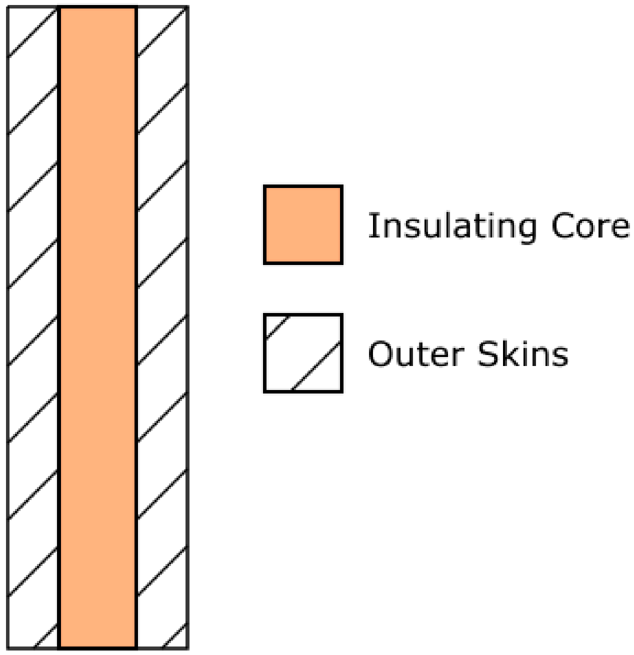

Figure 9. Structural insulated panel.

In the modern SIP, the core of paperboards has been replaced with rigid foam insulation such as polyurethane foam or expanded polystyrene, and wythes are usually constructed from oriented strand boards, cement fibre, calcium silicate, or metal. Unlike timber frame panels, they create a continuous layer of insulation without thermal bridges caused by timber studs. SIPs are constructed from paperboards sandwiched between plywood, and their inherent thermal qualities and airtightness delivered through precision in the factory environment allow them to meet high energy standards, such as Passive Haus since the early 2000s [127]. While oriented strand board (OSB) is the cheapest skin option, its reaction to moisture limits its use as a facing material, and higher durability and fire protection can be obtained using other materials. However, one of the significant benefits of SIPs is their reduced weight compared to conventional wall systems, which can significantly lower the dead load [128].

Cross-Laminated Timber

Developed in the 1970s, cross-laminated timber (CLT) is a type of engineered timber that can be used to construct closed panels. CLT panels consist of multiple planks of kiln-dried softwood clued with adhesive at perpendicular angles. Each plank is usually strength graded to BS EN 14081-1 [129] to ensure consistent performance. The perpendicular alignment of timber grains increases both the structural strength and stability of the panels. A panel consists of an odd number of layers, and each layer may differ in thickness. The mechanical properties of CLT make it possible to use it in medium- and high-rise buildings as a lighter alternative to concrete and steel [130]. The cellular structures of the timber act as a natural insulator, giving it thermal advantages over many other materials used for load-bearing walls. Unlike standard timber-frame buildings, CLT panels do not suffer from repeating thermal bridges caused by timber studs. The addition of insulation material to a wall element increases the overall thickness of the wall but results in a more consistent thermal transmittance [131].

CLT buildings are constructed one level at a time, with wall panels held temporarily by formwork while the floor panels are put into position and secured. During construction, the panels can be secured parallel to the external walls by hangers to serve as infill panels or held together by timber joists supported by load-bearing walls, timber ring beams, and timber blocking between the joists [132]. One concern regarding the use of combustible building materials, particularly in taller structures, is fire safety. Timber combusts at 200–300 °C when flammable gaseous compounds caused by molecules splitting react with oxygen [133]. However, timber also possesses inherent fire resistance due to the charring that forms as the compounds decompose. The charring acts as a thermal insulator, limiting the temperature rise and extending the duration for which the unburnt timber core will maintain its structural integrity [134]. Internally, fire-resistant gypsum plasterboards can be used to reduce the total fire load from combustible materials, limiting the spread of fire to a single room in residential multi-storey CLT buildings [135]. Despite a growing demand for cross-laminated timber (CLT) in the U.K., the majority of CLT production currently takes place in other European countries. The feasibility of CLT production is heavily influenced by the availability of timber sources and kiln-drying facilities that can meet the drying requirement. In 2014, it was uncommon for the U.K.'s sawmill industry to kiln-dry timber below 18–20% moisture content compared to the 12± 3% in other European countries. An experiment with the most dominant softwood in Scotland, Sitka spruce, produced inferior CLT walls only able to satisfy the buckling design criteria at 85.6% capacity of its European counterpart [136].

Volumetric

Volumetric (modular) construction is a novel off-site method that involves pre-building units completely before transporting them to the construction site. This approach enables construction to occur in controlled environments where the same materials are prefabricated to meet uniform building standards. By developing and installing these three-dimensional modules, waste is reduced, weathering effects are eliminated, safer work environments are created, and infinite design possibilities are offered [137].

Pods

The increasing popularity of pods within the construction industry can be attributed to their introduction in student accommodation and hotels. Assembled rooms are slotted into already standing structures, such as bathrooms and kitchens, making them an example of volumetric construction. Typically, pods are non-loadbearing and made off site from concrete, timber, or steel, and can be added either by crane or externally via gaps in the cladding. While available in multiple materials, the standard pod is often composed of a steel frame with plasterboard and plywood, offering robustness and low maintenance while allowing flexibility for the overall design. Produced off site on different scales, the logistics of pod production must be carefully organised. Storing pods on site before the superstructure is fully erected is not recommended due to its impracticality. Adjustments cannot be made as freely with any volumetric process, unlike on-site construction. Therefore, meticulous planning should be taken with regard to the foundations, ensuring that when the pods are slotted in, all connections meet precisely, and no unwanted gaps exist [138].

3. Building Regulations from the Past Decades to 2021

3.1. Definition and Purpose

The imperative for national building regulations in the U.K. is indisputable, stemming from the profound legacy of buildings' materials and construction methods. These regulations are essential to ensuring safety, sustainability, and quality, fostering a resilient built environment. By establishing comprehensive guidelines, they drive innovation, informed decision making, and harmonised construction practices, leading to a built environment that balances historical wisdom with modern expertise, meeting present needs while safeguarding the future. The implementation of national building regulations in the U.K. has a long history. Scotland was the first country in the U.K. to implement national building regulations through the Building (Scotland) Act 1959 [139], and a national system was adopted in 1964 [140]. England and Wales followed suit with the Public Health Act 1961 [141], which led to the introduction of The Building Regulations 1965 [142]. However, building control existed before this in Scotland, with a dean guild court having jurisdiction in each Burgh as far back as AD 1119 [22]. In England, localised building regulations can be traced as far back as the 15th century, with concern given to derelict buildings, as they made it more difficult to collect taxes [143]. Over time, bye-laws became increasingly strict and less flexible. For instance, they outright prohibited the use of any combustible building materials for walls in London [144]. The control of buildings in England and Wales is primarily governed by the Building Act 1984 [145], while in Scotland, it is governed by the Building (Scotland) Act 2003 [146]. These principal statutes provide a foundation for the creation of secondary legislation, such as building regulations. The authority to make regulations for their respective countries is vested in the English Secretary of State, Welsh Ministers, and Scottish Ministers. The powers conferred upon them are largely the same, as can be observed by comparing Section 1(1) of the two acts:

Scotland, England, and Wales:

- Securing the health, safety, welfare, and convenience of persons in or about buildings and of others who may be affected by buildings or matters connected with buildings.
- Furthering the conservation of fuel and power [145,146].

England and Wales:

- Preventing waste, undue consumption, misuse or contamination of water.
- Furthering the protection or enhancement of the environment.
- Facilitating sustainable development.
- Furthering the prevention or detection of crime [145].

Scotland:

- Furthering the achievement of sustainable development [146].

The principal regulations for Scotland are the Building (Scotland) Regulations 2004 [147], whereas, for England and Wales, this is the Building Regulations 2010 [148]. These regulations are regularly amended, and just as an example of recent changes, the Building Regulations 2010 were amended in 2016, 2017, and 2018 for England [149]. Similarly, Welsh amendments were made in 2016, 2017, 2018, and 2019 [149]. The Building (Scotland) Regulations 2004 saw recent amendments in 2016, 2017, 2019, and 2020 [150]. Over time, building regulations in various countries have developed and matured. Although these regulations share many similarities from a political standpoint, differences still exist. Even within the U.K., differences exist between the building regulations of England and Wales, despite the Building Act 1984 serving as the principal statute for both countries. This is due to the transfer of reserved matters listed in Schedule 7A of the Government of Wales Act 2006 [151], which came into force in 2011 [152]. As part of this transfer, the power to create building regulations for Wales was transferred from the Secretary of State to the Welsh Ministers, effectively creating distinct building regulations for Wales. The power to approve and issue practical guidance on building regulations is granted to the Secretary of State or a designated body under Section 6(1) of the Building Act 1984 in England and Wales, while a similar power is granted to the Scottish Minister under Section 4(1) of the Building (Scotland) Act 2003 in Scotland. These guidance documents are known as Approved Documents and Building Standards Technical Handbooks, respectively, and provide guidance on how compliance with building regulations can be demonstrated. Although the two countries have similar documents, there are differences between them, which will be discussed in the following section.

3.2. Approved Documents and Technical Handbooks Differences

Welfare and convenience criteria are essentially the same in each country. Only minor differences exist, such as the height of electrical switches and sockets [153–155] or natural light requirements, where the glazed area of a room (except a kitchen, storage, or utility room) should be a minimum of 1/15th of the floor area in Scotland, while no requirement exists in the other countries [153,155,156]. Additionally, there are similarities in the safety of the occupants. Structural safety is the same in each country where the British Standards can be used to demonstrate compliance [153,157,158]. The protection of occupants from crime, harmful substances, and gases is also the same [99,153,159], but certain aspects, such as consent for water and sewage discharge, fall under different bodies. These bodies are the Environment Agency (England) [160], the Scottish Environment Protection Agency 158, and Natural Resources (Wales) after the devolution in 2013 [161,162]. However, there are notable differences in terms of fire and noise protection, which are discussed in Sections 3.2.1 and 3.2.2.

In each country of the U.K., conservation and sustainability are priorities, albeit with differing targets. The most notable differences lie in the conservation of energy, although minor variations exist in water conservation. For instance, Wales sets a higher requirement for sanitary flow rates. Moreover, the recognition of achieved sustainability is managed differently in Scotland when compared to England and Wales. The following sections highlight the differences between the countries in terms of fire and noise safety, conservation of energy, and recognition of achieved sustainability.

3.2.1. Fire Safety

Fire Resistance Duration (Structural and External Walls)

The fire safety requirements for buildings in the U.K. are based on the height of the topmost floor and are measured in minutes using the European fire-resistance classification system, REI. REI takes into account the load-bearing capacity (R), integrity (E), and thermal insulation (I) of the structural elements [163]. The countries of the U.K. have different requirements regarding the minimum REI duration for buildings of different heights. For instance, Scotland permits 30 REI up to 7.5 m, whereas England and Wales allow it only up to 5 m. Scotland has a higher standard of 120 REI for buildings over 18 m, while England and Wales only require 90 REI up to 30 m before using 120 REI [153,164,165]. In the case of a block of flats over a certain height, the REI alone is not enough, and sprinklers are mandatory. In England, sprinklers are required for buildings over 11 m, whereas Wales mandates sprinklers only for buildings above 30 m [166]. Conversely, in Scotland, automatic fire suppression systems are mandatory in all new flats, maisonettes, shared multi-occupancy residential buildings, and new social housing dwellings [153].

Wall Cladding Combustibility

The minimum requirement for wall cladding combustibility is defined with Euro Classes (see Appendix A) based on the height of the topmost floor of a dwelling or flat and its proximity to a boundary. The highest standard is currently set by Scotland, which is visible in Table 1.

Table 1. Wall cladding combustibility (dwellings and flats) [153,165,166].

Height	Scotland	England	Wales
<1 m of the boundary			
0–11 m	A2 [1]	B [2]	B [2]
11–18 m	A2	B [2]	B [2]
18 m+	A2	A2	A2
>1 m from the boundary			
0–10 m	B	No provision	No provision
10–18 m	A2	No provision	No provision
18 m+	A2	A2	A2

[1] Except where the cladding of a house achieves B and the wall behind the cladding has appropriate fire resistance on both sides. [2] Must have appropriate fire resistance on both sides.

Limitations on Unprotected Areas

To ensure fire safety, external walls must have a specified fire resistance duration. Unprotected areas, including windows and doors, are those that do not meet the specified fire resistance duration. Each country has set exact separation requirements for unprotected areas on external walls. However, differences exist in the permitted size of unprotected areas, which are determined by a calculation that considers the distance between the wall and a boundary. A notional boundary is influenced by the unprotected areas of an existing building, and Scotland does not allow unprotected areas (other than fascia, soffit, or barge board, or any cavity vents or solum vents) if the building is within 0.5 m of the boundary. In contrast, England and Wales allow unprotected areas as long as the rest of the wall is fire-resistant on both sides. Scotland also treats Class B, C, D, or E cladding as unprotected in the calculation, making it more challenging to meet the requirement. On the other hand, in England and Wales, external walls with appropriate fire resistance duration requirements are still calculated as unprotected if the surface material is lower than Class B, but the unprotected area is halved in these cases. There are other methods of calculation found in the BR 187 report by the British Research Establishment (BRE), which may demonstrate compliance [153,164,165].

Limitations on Roof Coverings

The resistance of roofs in each country is determined by tests conducted in either BS 476-3 [167] or BS EN 13501-5 [168]. The harmonised standards are used to describe the differences between the countries. The permitted distance of different roof types to a relevant boundary varies between the countries, with Scotland having more stringent regulations than England and Wales. For instance, highly vulnerable roofs such as EROOF and FROOF are not permitted within 24 m of the relevant boundary in Scotland, while in England and Wales, EROOF can be as close as 6 m to the boundary, and FROOF is allowed within 20 m of the boundary [153,164,165]. However, restrictions apply to the size of a dwelling, and dwelling houses in terraces of three or more houses are not permitted to have EROOF or FROOF. The fire safety regulations across the countries have a few minor differences. The internal lining requirements for rooms smaller than 4 m^2 are Class D, and those larger than 4 m^2 are Class C, and this standard is consistent in all countries [164,165]. However, in Scotland, rooms between 4 and 20 m^2 may have Class D internal lining, provided it does not exceed half of the floor area [153].

3.2.2. Noise Safety

The effect of noise through walls and floors from attached buildings or differently occupied parts of the same building is considered in each of the countries. They all set requirements for both impact ($L'_{nT,w}$) and airborne sound insulation ($D_{nT,w}$), but unlike Scotland [153], England and Wales also incorporate the spectrum adaptation term (Ctr) for airborne sound [169,170]. C_{tr} was introduced in the second edition of EN ISO 717-1 [171] and is used to account for low-frequency noise such as road traffic and disco music.

As C_{tr} is always a negative number, $D_{nT,w} + C_{tr}$ will always be lower than $D_{nT,w}$, thus making it more challenging to meet the airborne sound insulation requirement. Scotland's sound insulation standards are the highest compared to England and Wales, as shown in Table 2. In addition, Scotland has set even higher voluntary targets in recognition of its achieved sustainability. The use of adaptation significantly improves the correlation between subjective and objective evaluations of sound insulation, even down to 50 Hz [172].

Table 2. Noise (separating walls and floors in dwellings or flats) [153,169,170].

Height	Scotland	England	Wales
Minimum airborne sound insulation ($D_{nT,w}$) [1]	56 58 (Silver) [2] 60 (Gold) [2]	45	45
Maximum impact sound transmission ($L'_{nT,w}$)	56 54 (Silver) [2] 52 (Gold) [2]	62	62

[1] England and Wales includes C_{tr} dB. [2] Sustainability targets.

3.2.3. Conservation of Energy

The commitment to lowering energy consumption and carbon dioxide emissions is a priority in each of the countries, although their specific commitments differ. As indicated in Table 3, Scotland currently sets the highest standard in this area. One example of this commitment is reflected in the values used for the notional building in the SAP 2012. The values used in SAP have been repeatedly tightened over time, and this trend can be observed by comparing previous versions of the SAP. SAP 2012 calculates both the carbon dioxide emissions (kg CO_2/m^2/year) and fabric energy efficiency (kWh/m^2/year) for a proposed building, which is measured against the performance of a notional building.

Table 3. SAP 2012 values and area-weighted U-value limits [153,156,173].

	Scotland		**England**		**Wales**	
	Thermal Transmittance (W/m^{2}K)					
	SAP	**Limit**	**SAP**	**Limit**	**SAP**	**Limit**
External wall	0.17	0.22	0.18	0.3	0.18	0.21
Party wall	0 [1]	0.2 [1]	0–0.2 [2]	0.2	0–0.2 [2]	0.2
Floor	0.15	0.18	0.13	0.25	0.13	0.18
Roof	0.11	0.15	0.13	0.2	0.13	0.15
Windows	1.4	1.6	1.4	2.0	1.4	1.6
Doors	1.4	1.6	1.0–1.2 [3]	2.0	1.0–1.2 [3]	1.6
	Air Permeability (m^3/H·m^2 at 50 Pa)					
	SAP	Limit	SAP	Limit	SAP	Limit
Air permeability	7	–	5	10	5	10
	Miscellaneous SAP Values					
	SAP		SAP		SAP	
Thermal bridges	×0.08 total exposed surface area		SAP 2012 Appendix R references [156]		SAP 2012 Appendix R references [173]	
Wastewater heat recovery	Y		N		N	
Photovoltaic	Y [4]		N		N	
Thermal mass	Same as design		Medium (250 kJ/m^2K)		Medium (250 kJ/m^2K)	
Glazing orientation	East/West		Same as design		Same as design	

[1] Only cavity separating walls. [2] Solid and filled cavity walls use 0 W/m^2K, and unfilled cavity walls use 0.2 W/m^2K. [3] Opaque doors are 1.0 W/m^2K, and semi-glazed doors are 1.2 W/m^2K. [4] Only applies when an electric or biomass energy package is not used.

The three countries, England, Wales, and Scotland, have different approaches to the calculation of energy consumption and carbon dioxide emissions. In England, both energy consumption and carbon dioxide emissions calculations must be met to demonstrate compliance, while in Wales only carbon dioxide emissions calculation are used. In contrast, Scotland introduces fixed voluntary targets for fabric energy efficiency to recognise achieved sustainability. To demonstrate compliance, both the dwelling emission rate (DER) and the dwelling fabric emission efficiency (DFEE) must be lower than their corresponding target emission rate (TER) and target fabric energy efficiency (TFEE), respectively. The TFEE is determined by taking the fabric energy efficiency of the notional building and adding 15% [156]. These calculations are performed twice, for both the design and the completed building. However, a single calculation increases the design flexibility and risks poor design, so to address this, Wales and Scotland set stricter area-weighted average thermal transmittance (U-values) limits. These calculations have a direct impact on the design flexibility and energy efficiency of buildings, and it is crucial to comply with the regulations to reduce carbon dioxide emissions and achieve sustainable development [153,173]. Scotland stands out from other countries in its assumption of renewables in the notional building. Photovoltaics and wastewater heat recovery are included, unless an electric or biomass energy package is used. Failure to incorporate these technologies makes it more difficult to meet the carbon emission target in Scotland than in England and Wales for proposed buildings using gas [153,156,173]. Table 3 summarises the main differences between countries in terms of the values used for the notional building and the area-weighted U-value limits.

3.2.4. Recognition of Achieved Sustainability

The recognition of achieved sustainability is different in Scotland compared to England and Wales. In Scotland, the Building (Scotland) Amendment Regulations 2011 [174] introduced sustainability labelling to give credit to meeting or exceeding the building regulations. There are currently four tiers (Bronze, Silver, Gold, and Platinum), further divided into targets for carbon dioxide emissions, energy for heating, water use efficiency, and more. Unlike Scotland, the building regulations in England and Wales have yet to incorporate such recognition of sustainability. However, a level of recognition was found in the Code for Sustainable Homes before it was withdrawn in 2015. Recognition is therefore found through other voluntary assessments, such as the Home Quality Mark by the BRE group.

4. Discussion and Conclusions

The present research conducts a comprehensive examination and evaluation of the compatibility of the discussed building methods and materials with contemporary building regulations. This evaluation was informed by a close study of current compliance standards and guidelines from reputable sources, such as the International Building Code (IBC), the British Standards Institution (BSI), and the European Committee for Standardisation (CEN). By aligning the investigation with these authoritative references, it is ensured that the presented methods and materials adhere to the latest industry requirements and best practices. Furthermore, it is considered the impact of technological advancements and innovations on the continued relevance and applicability of these methods in modern construction practices. Notably, studies by reputable scholars have emphasised integrating technological advancements into building methods to enhance compliance and efficiency. This meticulous examination of compatibility provides readers with valuable insights into the extent to which these methods and materials meet current compliance standards and may contribute to sustainable construction practices.

Throughout history, building construction methods have continuously been evolving to adapt to new conditions and requirements. With advancements in knowledge and technology, these methods have become increasingly sophisticated and energy-reliant. Traditional and modern construction methods have been abandoned and revived in renewed hope that their properties can address current challenges, such as providing shelter, addressing resource and labour shortages, or lowering CO_2 emissions to prevent climate change. As building construction has progressed, many of these challenges have been imposed under different regulations and standards, which in turn have become more comprehensive. The materials used for construction have also evolved, with a wide range of materials available with varying properties that are chosen based not only on their properties but also factors such as availability and cost. Initially, natural materials were chosen based on their ease of sourcing and a limited understanding of their properties. Even today, the types of qualities desired in building materials can be found in the natural materials used thousands of years ago. The main qualities that are desired in building materials include thermal resistance, durability, strength, and fire resistance. Throughout history, the required material strength to construct medium- and high-rise buildings has been available. Natural stone, for example, possesses compression strength that even surpass that of many modern construction materials, such as concrete. Moreover, engineered timber, such as CLT, can meet current construction standards. Therefore, limitations in vertical construction primarily stemmed from a lack of knowledge and tools rather than unavailable materials. However, earthen structures do not possess sufficient compressive strength and rely heavily on wall thickness, thus severely limiting their vertical application and creating potentially unsafe environments. While stabilised RE has improved its strength, unconventional techniques such as earthen construction face other barriers beyond structural strength. Regulations mandate that all buildings withstand dead loads and remain stable under imposed loads such as wind and snow for occupants' and bystanders' safety. Unlike conventional construction methods, unconventional methods lack British Standards and Eurocodes, making it more challenging to obtain approval, further hindering adoption. Durability is a key requirement for construction materials, as demonstrated by the still-standing historic buildings made of sandstone, brick, and earth. Concrete has also proven to be durable, especially with advancements in offsite manufacturing. However, the longevity of all construction materials depends on their environmental conditions and maintenance. The regulations do not mandate a specific level of porosity for materials but recognise that moisture can cause damage to structural elements and insulation if trapped or penetrating through. As a result, building regulations require that occupants and buildings be protected from precipitation and ground moisture. Proper execution is essential for the use of high-porosity materials such as sandstone to avoid deterioration of the stone and internal wall elements. Wind-driven rain is a particular concern for RE structures, as it can directly damage external surfaces and raise questions about their compliance with regulations. Adequate cladding, vapor barriers, and cavities can prevent the decay of structural elements. In contrast, traditional buildings such as cordwood rely on exposing log ends to release moisture, which may not be suitable for high-humidity climates. Structural integrity in RE buildings may be compromised as the moisture ratio increases. Failure to consider the fire behaviour of building materials has cost many lives and stretched the importance of regulations. The main area of interest from a regulatory point of view is the material's reaction and resistance to fire. Strict byelaws would have prohibited the use of combustible materials such as straw and timber. This strictness has been lessened in modern regulations, which instead consider multiple factors to determine whether materials may be used. In the U.K., fire safety regulations for building construction have recently been aligned between England, Wales, and Scotland. While low-rise construction using traditional methods of construction may encounter few regulatory restrictions regarding the combustibility of external wall cladding, its use is limited in closely populated areas due to sizing restrictions related to notional boundaries and unprotected areas. In high-rise construction, the use of combustible materials for external cladding is no longer permitted across the U.K. The combustible materials discussed in this paper, with the exception of timber, would have limited use in high-rise structures due to their structural strength. The Euro class A1 or A2 requirement has implications for CLT over 18 m in Wales and England and over 11 m in Scotland. Though this is not a ban on CLT construction, consideration must be given to both the use of a non-combustible wall cladding material and the separation between structural CLT elements and the external cladding. The materials with the highest compression strengths, such as sandstone and concrete, are also among the ones exhibiting the best fire safety properties. The inherent fire resistance of some natural materials, despite their combustibility, coupled with the thickness of their walls and a fire-resistant render, allow them to meet the regulatory criteria for low-rise buildings. However, earthen structures pose a challenge in terms of fire resistance due to the tendency of cracks to form from shrinkage. These cracks create paths for fire to spread through the wall element, a problem exacerbated by the addition of straw to the wall mixture. Therefore, the use of earthen materials in construction raises questions about their suitability for meeting fire safety regulations.

The importance of energy efficiency in buildings has increased significantly in recent years, particularly due to concerns about global warming. Building regulations have been amended to reflect this, with a focus on the thermal properties of materials and their impact on overall energy consumption. As a result, the thermal performance of individual materials and wall elements has become a crucial factor to consider in construction. Table 4 provides a comparison of the thermal performance of different methods of construction, highlighting their potential to contribute to efforts to tackle climate change.

The thermal properties of materials used in traditional construction are generally poor insulators, with the exception of straw bales, cordwood, and hempcrete. While their high wall thickness compensates for this to some extent, they still heavily rely on additional insulation to meet building regulations. In modern RE construction, the stabiliser used to improve structural strength further exacerbates this issue. The lack of standardisation in soil mixtures used for earthen buildings also leads to significant variations in additional insulation requirements between builds. High-density materials such as brick, stone, and concrete exhibit high thermal conductivity. The incorporation of mortar in cordwood leads to significant thermal bridges due to the alignment of the log ends. In modern construction, there has been a move towards thinner wall structures, following the post-war era attempt to tackle resource shortages. However, due to the lower thermal conductivity of air compared to materials such as sandstone and brick, the reduction of materials in cavity walls did not hinder thermal performance. Recent amendments made to building regulations reflect the increasing importance of energy efficiency in tackling climate change. Table 4 compares the thermal performance of individual materials and wall elements in different methods of construction, highlighting their role in improving energy efficiency.

As an exemplary case study of building elements shown in Appendix C, the performance of the external wall, which has been constructed using a diverse range of materials and methods, is meticulously presented and analysed. Through a rigorous comparison with the recommended standards set forth in the prevailing regulations (SAP value), the study provides a comprehensive assessment of the performance exhibited by each material and construction method employed. This deliberate inclusion of such a detailed analysis offers an unparalleled opportunity to thoroughly evaluate the effectiveness and efficiency of various materials and methods in meeting regulatory guidelines. By scrutinising their performance characteristics and benchmarking them against established standards, it gains invaluable insights into areas that demand further enhancement and optimisation. The thermal characteristics of building materials, particularly their thermal conductivity, play a significant role in determining a building's energy storage capacity. Integrating diverse building materials into alternative construction methods can have a profound impact on meeting current building regulations. However, this integration necessitates a comprehensive investigation to address additional considerations beyond energy efficiency, such as acoustic performance and fire safety. The selection and utilisation of appropriate building materials are critical for achieving desired energy performance outcomes. Variations in thermal conductivity significantly affect a building's ability to store and dissipate heat, influencing overall energy efficiency. By carefully considering the thermal properties of different materials, including insulation and heat conduction, designers and practitioners can optimise energy performance while ensuring compliance with regulatory standards. To comply with regulations, deliberate combinations of materials within alternative construction methods offer a viable solution, leveraging unique properties to enhance overall performance. Rigorous analysis is necessary to address concerns related to material combinations, for example, acoustic performance and fire safety. Unlocking the full potential of material integration requires further research, experiments, and assessments to evaluate performance and inform decision-making for optimal energy efficiency and occupant comfort.

Table 4. Thermal performances of materials and methods of construction.

Category		Type	Material	Building Envelope Properties (Calculated Values) Thermal Conductivity (W/m-K)	Thickness (mm)	Thermal Resistance (m^2K/W)	Calculated U-Value (W/m^2K)	In-Situ Measurements In-Situ Thickness (mm)	In-Situ U-Values (W/m^2K)
Traditional	Earth	Rammed Earth	Earth	1.5 [175,176]	300	0.2	2.70	300	1.9–2 [177]
		Cob	Lime render	0.8 [178]	35	0.044	1.12	482–502	0.9–1.02 [178]
			Cob	0.73 [178]	500	0.68			
	Wood	Straw Bale	Lime render	0.8 [178]	35	0.044	0.11	435	0.16 [178]
			Straw	0.051 [52,179]	450	8.82			
			Lime render	0.8 [178]	35	0.044			
		Cordwood	Wood	0.13 [175]	600	4.62	0.21	610	0.16 [57]
			Cement mortar	2.15 [180]	600	0.28	2.2		
	Masonry	Adobe	Earth render	1.5 [175]	35	0.023	0.81	350	1.07 [181]
			Adobe Brick	0.24 [62]	250	1.04			
		Clay Brick	Brick	0.77 [182]	102.5	0.13	1.18	265	1.1–1.3 [91]
			Air cavity	0.18 [182]	75	0.42			
			Brick	0.77 [182]	102.5	0.13			
		Hempcrete	Lime render	0.8 [178]	15	0.019	0.39	210	0.4 [178]
			Hempcrete	0.09 [80]	210	2.33			
			Lime render	0.8 [178]	15	0.019			
		Sandstone	Sandstone	2.3 [175]	550	0.24	2.44	550	1.4 [91]
Modern	Masonry	Concrete	Reinforced (2% steel and 2400 kg/m^3)	2.5	200	0.08	4	–	–
			High density (2400 kg/m^3)	2	200	0.075	3.7		
			Medium (2000 kg/m^3)	1.35	200	0.11	3.14		
	Wood	Timber Frame	Brick	0.77 [182]	102.5	0.13	0.25	–	–
			Air cavity	0.18 [182]	50	0.28			
			Mineral fibre	0.04	140	3.5			
			Brick	0.77 [182]	102.5	0.13	0.6		
			Air cavity	0.18 [182]	50	0.28			
			Timber frame/studs	0.13 [175]	140	1.08			
		SIP	Brick	0.77 [182]	102.5	0.13	0.13	–	–
			Air cavity	0.18 [182]	50	0.28			
			OSB	0.13 [175]	12	0.09			
			Mineral fibre	0.04	270	6.75			
			OSB	0.13 [175]	12	0.09			
		CLT	Timber (500 kg/m^3)	0.13 [175,183]	100	0.77	1.06	100 (+200) [1]	0.114 [184]

[1] 100 mm CLT plus 200 mm wood fibre with thermal conductivity of 0.038.

The substitution of inner masonry components with timber framing has resulted in a substantial enhancement in thermal performance within the construction system. This transition to timber framing has yielded notable benefits, including improved insulation properties, reduced thermal bridging, and enhanced energy efficiency, thereby contributing to more sustainable and environmentally conscious building practices. This has made it possible to replace the poor-performing element with high-performing insulation material between timber studs without increasing the wall thickness. This similar reduction in solid materials while maintaining the required structural strength can be seen in CLT and SIP. These techniques further address the thermal bridge issue found in timber framing, which is highlighted in Table 4. The utilisation of these construction methods not only offers a high degree of flexibility but also enables the effective fulfilment of diverse requirements by facilitating the incorporation of various insulation materials, plasterboards, and membranes. This inherent adaptability allows for tailored solutions that can address specific thermal, acoustic, and fire safety demands, ensuring optimal performance and compliance with regulatory standards. By leveraging the versatility of these methods, designers and practitioners can create customised building envelopes that maximise energy efficiency, enhance occupant comfort, and mitigate potential risks, thereby exemplifying the dynamic nature of contemporary construction practices.

Modern methods of construction involve more than just a reduction in materials and increased insulation. A significant improvement in heat loss reduction has been achieved through increased air tightness, which is facilitated by the precision and quality control measures applied in the factory environment. The shift towards off-site manufacturing in modern construction methods has resulted in a significant improvement in various phases of construction, including time, quality, and cost. This approach allows for the production of building components in a controlled environment, leading to higher precision and quality. The construction time has also been reduced due to the elimination of obstacles that typically affect on-site construction, such as adverse weather conditions. In contrast, traditional natural construction methods were frequently hindered by their slow drying time, leaving the structure vulnerable during this period.

Recommendation

It should be noted that the paper presents construction methods but does not attempt to address all structural engineering aspects. Additionally, while the adverse effects of noise have been linked to the construction, the paper does not focus on sound insulation. Finally, it is important to acknowledge that life cycle assessment (LCA) was not considered in this study. The utilisation of timber in off-site manufacturing processes is a promising solution for addressing the current housing shortage. This manufacturing method not only offers the desired properties for construction but also has the potential to significantly reduce construction time. Specifically, England and Wales are poised to see substantial benefits from a deeper understanding of timber construction. It is essential to recognise that past failures of off-site manufacturing should not be taken as an indication of present outcomes, as advancements in technology and techniques have significantly improved the quality of timber construction. Educating the public about the benefits of timber construction is paramount to ensuring that past pitfalls do not recur. The recent reminder of the implications of combustible materials must not become a barrier, as the concerns of rot did in the past, to the utilisation of timber. As evidenced in this paper, timber construction can meet the fire safety requirements set forth in regulations. The use of natural materials in contemporary construction remains a promising avenue for development. Self-build projects using straw bales and hempcrete have the potential to alleviate the burden on the construction industry. These techniques could benefit from increased standardization to make the project more approachable and achievable.

In the next study, we will examine the applicability of solutions to low- and high-rise construction and their alignment with the industry. This analysis will consider labour costs, required skills, time efficiency, quality control, and environmental impact. Evaluating these factors provides a comprehensive understanding of practical implications, challenges, economic feasibility, required expertise, project timelines, and sustainability. Additionally, an in-depth LCA study will assess material availability, production, and origin to strengthen the argument. Scrutinising quality control ensures durability and safety. This systematic analysis offers a robust evaluation and valuable information for industry professionals and decision makers considering construction method implementation.

Author Contributions: Conceptualization, R.V. and B.V.; methodology, R.V., A.M. and B.V.; investigation, R.V., A.M. and B.V.; resources, R.V., A.M., B.V. and L.T.; writing—original draft preparation, R.V., A.M. and B.V.; supervision, B.V. and L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partly funded by the European Commission Erasmus+ Programme, project "Design and Construction of Environmental High Performance Hybrid Engineered Timber Buildings" (HybridTim), No. 2020-1-DK01-KA203-075045.

Data Availability Statement: The data utilized in this work have been obtained from various reliable sources, including journal articles, conference papers, building regulations, and standards, which are appropriately referenced.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. European Reaction to Fire Classification

For the U.K. and E.U., fire testing and classification of construction products have been harmonised in the BS EN 13501-1 "Fire classification of construction products and buildings elements". Combustibility is considered under Reaction to Fire, which is the response of a product in contributing by its own decomposition to a fire to which it is exposed under specified conditions.

The classification used in this system is also referred to as Euro classes. A Euro class is made up of three classes, the main class considering combustibility and contribution to fire, a second class focusing on smoke, and a third class focusing on burning droplets. The main class ranges from A1, A2, B, C, D, E, or F, with A1 being the highest performance (see Table A1).

Table A1. Euro classes.

Classification	Combustibility	Contribution
A1	Non-combustible	No contributing to fire growth or a fully developed fire
A2	Very Limited combustibility	No significant contribution to the fire load and fire growth
B	Combustible	Same as C but more stringent requirements
C	Combustible	Same as D but more stringent requirements and under thermal attack by a single item they are limited to lateral spread of flame
D	Combustible	Capable of resisting a smaller flame for a longer duration without substantial spread.
E	Combustible	Minor flame attacks can be resisted without substantial spread for a short period
F	Combustible	The reaction to fire cannot be determined

Appendix B. European Resistance to Fire Classification (Roofs)

BS EN 13501-5 [168] provides harmonised fire classification for roof coverings based on the four tests in ENV 1187 [185]. The principal test conditions are:

- Test 1 (t1)—with burning brands.
- Test 2 (t2)—with burning brands and wind.
- Test 3 (t3)—with burning brands, wind and supplementary radiant heat.
- Test 4 (t4)—a two-stage test that incorporates burning brands, wind and supplementary radiant heat [185].

The t1, t2, t3, and t4 are applied as suffixes to the classification to indicate which test was used. The necessity for different tests is due to the differing regulations in European countries and t4 is used in the U.K. The classifications for the results of these tests are B_{ROOF} (t4), C_{ROOF} (t4), D_{ROOF} (t4), E_{ROOF} (t4), and F_{ROOF} (t4), where the B_{ROOF} (t4) is the highest rating and BROOF (t4) is the lowest rating (see Table A2).

Table A2. Euro standards roof types [153,168].

Classification	Description	Vulnerability
B_{ROOF} (t4)	• No penetration of roof system within 60 min. • In preliminary test, after withdrawal of the test flame, specimens burn for less than 5 min. • In preliminary test, flame spread is less than 0.38 m across region of burning.	Low
C_{ROOF} (t4)	• In preliminary test, flame spread is less than 0.38 m across region of burning. • In preliminary test, after withdrawal of the test flame, specimens burn for less than 5 min. • In preliminary test, after withdrawal of the test flame, specimens burn for <5 min.	Medium
D_{ROOF} (t4)	• Roof system is penetrated within 30 min, but is not penetrated in the preliminary test. • In preliminary test, after withdrawal of the test flame, specimens burn for less than 5 min. • In preliminary test, flame spread is less than 0.38 m across region of burning.	Medium
E_{ROOF} (t4)	• Roof system is penetrated within 30 min but is not penetrated in the preliminary test. • Flame spread is not controlled.	High
F_{ROOF} (t4)	• No performance determined.	High

Appendix C. External Wall Properties in Comparison with SAP 2012

Table A3 compares the thermal performance of different construction methods against the u-values for external walls used in the SAP 2012, highlighting their potential in combating climate change.

Table A3. Comparison of u-values for external walls with SAP 2012 [153,156,173].

				External Wall Properties (Calculated Values) [1]				SAP 2012
Category	Type	Material	Thermal Conductivity (W/m-K)	Material Thickness (mm)	Thermal Resistance (m^2K/W)	Total Width (mm)	U-Value (W/m^2K)	In Comparison with 0.017 W/m^2K (%)
Traditional / Earth	Rammed Earth	Earth	1.5 [175,176]	300	0.2	400 [2]	0.38 [2]	−123.5%
Traditional / Earth	Cob	Lime render	0.8 [178]	35	0.044	635 [2]	0.32 [2]	−88.24%
		Cob	0.73 [178]	500	0.685			
Traditional / Wood	Straw Bale (No additional insulation)	Lime render	0.8 [178]	35	0.044	520	0.11	35.29%
		Straw	0.051 [52,179]	450	8.824			
		Lime render	0.8 [178]	35	0.044			
Traditional / Wood	Cordwood	Wood/ Mortar	0.13 [175]/ 2.15 [180]	600	4.458 [3]	700 [2]	0.22 [2]	−29.41%
Traditional / Masonry	Adobe	Earth render	1.5 [175]	35	0.023	385 [2]	0.29 [2]	−70.59%
		Adobe brick	0.24 [62]	250	1.042			
Traditional / Masonry	Clay Brick (Cavity wall)	Brick	0.77 [182]	102.5	0.133	380 [2]	0.32 [2]	−88.24%
		Air cavity	0.18 [182]	75	0.417			
		Brick	0.77 [182]	102.5	0.133			
Traditional / Masonry	Hempcrete	Lime render	0.8 [178]	15	0.188	340 [2]	0.19 [2]	−11.76%
		Hempcrete	0.09 [80]	210	2.33			
		Lime render	0.8 [178]	15	0.188			
Traditional / Masonry	Sandstone	Sandstone	2.3 [175]	550	0.239	650 [2]	0.37 [2]	−117.65%

Table A3. *Cont.*

				External Wall Properties (Calculated Values) [1]					SAP 2012
Category		**Type**	**Material**	**Thermal Conductivity**	**Material Thickness**	**Thermal Resistance**	**Total Width**	**U-Value**	**In Comparison with 0.017 W/m^{2}K**
				(W/m-K)	**(mm)**	**(m^{2}K/W)**	**(mm)**	**(W/m^{2}K)**	**(%)**
Modern	Masonry	Concrete [4]	Reinforced (2% steel and 2400 kg/m^3)	2.5 [175]	200	0.08	300 [2]	0.4 [2]	−135.29%
			High density (2400 kg/m^3)	2 [175]	200	0.1	300 [2]	0.39 [2]	−129.41%
			Medium (2000 kg/m^3)	1.35 [175]	200	0.148	300 [2]	0.39 [2]	−129.41%
	Wood	Timber Frame (No additional insulation)	Brick	0.77 [182]	102.5	2.392 [5]	252.5	0.42	−147.06%
			Air cavity	0.18 [182]	50				
			Timber frame with insulation infill	0.13 [175]/ 0.044	100				
		SIP (No additional insulation)	Brick	0.77 [182]	102.5	0.133	348.5	0.21	−23.53%
			Air cavity	0.18 [182]	50	0.278			
			OSB	0.13 [175]	12	0.092			
			Insulation	0.044 [6]	172	3.909			
			OSB	0.13 [175]	12	0.09			
		CLT	Timber (500 kg/m^3)	0.13 [175,183]	100	0.769	200 [2]	0.31 [2]	−82.94%

[1] All values have been calculated in accordance with BS EN ISO 6946:2017 [186]. [2] Includes 100 mm additional internal insulation with a thermal conductivity of 0.044 W/m-K. [3] A mortar-to-wood ratio of 1:5 has been assumed. Repeating thermal bridges have been calculated in accordance with BS EN ISO 6946:2017. [4] Density and reinforcement vary depending on structural specifications for the individual tunnel form, precast, flat slab or hybrid concrete project. [5] Repeating thermal bridges caused by studs have been calculated in accordance with BS EN ISO 6946:2017. A timber-to-insulation ratio of 3:20 has been assumed. [6] Insulation with significantly lower thermal conductivity is available which will greatly improve the performance.

References

1. Maher, L.A.; Richter, T.; Macdonald, D.; Jones, M.D.; Martin, L.; Stock, J.T. Twenty Thousand-Year-Old Huts at a Hunter-Gatherer Settlement in Eastern Jordan. *PLoS ONE* **2012**, *7*, e31447. [CrossRef] [PubMed]
2. Ritchie, A.; Bramwell, D.; Collins, G.H.; Dickson, C.; Evans, J.G.; Henshall, A.S.; Inskeep, R.; Kenward, H.; Noddle, B.A.; Vaughan, M.; et al. Excavation of a Neolithic farmstead at Knap of Howar, Papa Westray, Orkney. *PSAS* **1984**, *113*, 40–121. [CrossRef]
3. Childe, V.; Paterson, J.; Bryce, T. Provisional Report on the Excavations at Skara Brae, and on Finds from the 1927 and 1928 Campaigns. With a Report on Bones. *PSAS* **1929**, *63*, 225–280. [CrossRef]
4. Simpson, I.A.; Guttmann, E.B.; Cluett, J.; Shepherd, A. Characterizing anthropic sediments in north European Neolithic settlements: An assessment from Skara Brae, Orkney. *Geoarchaeology* **2006**, *21*, 221–235. [CrossRef]
5. Hill, J.D. The Pre-Roman Iron Age in Britain and Ireland (ca. 800 B.C. to A.D. 100): An Overview. *J. World Prehistory* **1995**, *9*, 47–98. [CrossRef]
6. Crone, A.; Cavers, G.; Allison, E.; Davies, K.; Hamilton, D.; Henderson, A.; Robertson, J.; Roy, L.; Whitehouse, N. Brutish and Short? The Life Cycle of an Iron Age Roundhouse at Black Loch of Myrton, SW Scotland. *J. Wetl. Archaeol.* **2018**, *18*, 138–162. [CrossRef]
7. Mytum, H.; Meek, J. Experimental archaeology and roundhouse excavated signatures: The investigation of two reconstructed Iron Age buildings at Castell Henllys, Wales. *Archaeol. Anthr. Sci.* **2020**, *12*, 78. [CrossRef]
8. Armit, I.; Ginn, V. Beyond the Grave: Human Remains from Domestic Contexts in Iron Age Atlantic Scotland. *Proc. Prehist. Soc.* **2007**, *73*, 113–134. [CrossRef]
9. Vitruvius; Morgan, M.H. *The Ten Books on Architecture*; Dover Publications: New York, NY, USA, 1960.
10. Dyer, C. Building in Earth in Late-Medieval England. *Vernac. Archit.* **2008**, *39*, 63–70. [CrossRef]
11. Perring, D. *The Roman House in Britain*; Routledge: London, UK, 2002; p. 253.
12. Thurley, S. *The Building of England: How the History of England Has Shaped Our Buildings*; William Collins: London, UK, 2013.
13. Wilson, P.; McMillan, A.; Maxwell, L.; Young, M. *Building with Scottish Stone*; Arcamedia & Natural Stone Institute: Edinburgh, Scotland, 2004.
14. UK Parliament. *An Act for Rebuilding the City of London*; UK Parliament: London, UK, 1667.
15. Schofield, J. Buildings in the City of London after the Great Fire of 1666. *Int. J. Histor. Archaeol.* **2021**, *26*, 401–433. [CrossRef]
16. Hashemi, A. Review of the UK housing history in relation to system building. *Alam. Cipta.* **2013**, *6*, 47–58.

17. Department for Business, Energy & Industrial Strategy. 2019 UK Greenhouse Gas Emissions, Final Figures. 2021. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/957887/2019_Final_greenhouse_gas_emissions_statistical_release.pdf (accessed on 23 March 2023).
18. Department for Business, Energy & Industrial Strategy. Electricity: Commodity Balances (DUKES 5.1). 2021. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1094628/DUKES_2022_Chapter_5.pdf (accessed on 23 March 2023).
19. United Nations Paris Agreement. 2015. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 10 March 2023).
20. Department for Business, Energy & Industrial Strategy. United Kingdom of Great Britain and Northern Ireland's Nationally Determined Contribution. 2022. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943618/uk-2030-ndc.pdf (accessed on 23 March 2023).
21. Scottish Parliament. Climate Change (Emissions Reduction Targets) (Scotland) Act. 2019. Available online: https://www.legislation.gov.uk/asp/2019/15/enacted (accessed on 23 March 2023).
22. Bett, G.; Hoehnke, F.; Robison, J. *The Scottish Building Regulations: Explained and Illustrated*, 3rd ed.; Blackwell Science: Malden, MA, USA, 2003.
23. British Research Establishment. The Government's Standard Assessment Procedure for Energy Rating of Dwellings. 2014. Available online: https://files.bregroup.com/SAP/SAP-2012_9-92.pdf (accessed on 23 March 2023).
24. Fire Brigades Union. The Grenfell Tower Fire: A Crime Caued by Profit and Deregulation. 2019. Available online: https://www.regulation.org.uk/library/2019-FBU-The_Grenfell_Tower_Fire-A%20crime-caused_by_profit_and_deregulation.pdf (accessed on 21 March 2023).
25. Hackitt, J. Building a Safer Future: Independent Review of the Building Reguatlions and Fire Safety: Final Report. 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707785/Building_a_Safer_Future_-_web.pdf (accessed on 21 March 2023).
26. The Building (Amendment) Regulations. 2018. Available online: https://www.legislation.gov.uk/uksi/2018/1230/contents/made (accessed on 23 March 2023).
27. The Building (Amendment) (Wales) Regulations 2019. Available online: https://www.legislation.gov.uk/wsi/2019/1499/contents/made (accessed on 21 March 2023).
28. The Building (Scotland) Amendment Regulations 2020. Available online: https://www.legislation.gov.uk/ssi/2020/275/regulation/2/made (accessed on 23 March 2023).
29. Office for National Statistics. Dwelling Stock by Tenure, UK Dataset. 2022. Available online: https://www.ons.gov.uk/peoplepopulationandcommunity/housing/datasets/dwellingstockbytenureuk (accessed on 21 March 2023).
30. Piddington, J.; Nicol, S.; Garrett, H.; Custard, M. The Housing Stock of The United Kingdom. 2020. Available online: https://files.bregroup.com/bretrust/The-Housing-Stock-of-the-United-Kingdom_Report_BRE-Trust.pdf (accessed on 23 March 2023).
31. NHBC Foundation. House Building: A Century of Innovation. Technical Advances in Conventional Construction. 2019. Available online: https://www.nhbcfoundation.org/wp-content/uploads/2019/10/NF85_House-building-innovation.pdf (accessed on 23 March 2023).
32. Fratini, F.; Pecchioni, E.; Rovero, L.; Tonietti, U. The earth in the architecture of the historical centre of Lamezia Terme (Italy): Characterization for restoration. *Appl. Clay Sci.* **2011**, *53*, 509–516. [CrossRef]
33. Jaquin, P.; Augarde, C.; Gerrard, C. A chronological description of the spatial development of rammed earth techniques. *Int. J. Archit. Herit.* **2008**, *2*, 377–400. [CrossRef]
34. Kianfar, E.; Toufigh, V. Reliability analysis of rammed earth structures. *Constr. Build. Mater.* **2016**, *127*, 884–895. [CrossRef]
35. Jaquin, P.; Augarde, C.; Gallipoli, D.; Toll, D. The strength of unstabilised rammed earth materials. *Géotechnique* **2009**, *59*, 487–490. [CrossRef]
36. Ávila, F.; Puertas, E.; Gallego, R. Characterization of the mechanical and physical properties of unstabilized rammed earth: A review. *Constr. Build. Mater.* **2021**, *270*, 121435. [CrossRef]
37. Heathcote, K.A. Durability of earthwall buildings. *Constr. Build. Mater.* **1995**, *9*, 185–189. [CrossRef]
38. Skinner, F.G.; The Cob Buildings of Devon 1. Exeter: Devon Historic Building Trust. 1992. Available online: https://www.devonearthbuilding.com/leaflets/cob_buildings_of_devon_1.pdf (accessed on 23 March 2023).
39. Watson, L.; McCabe, K. La técnica constructiva del cob. Pasado, presente y futuro. *Inf. Constr.* **2011**, *63*, 59–70. [CrossRef]
40. Rios, J.A.; O'Dwyer, D. Experimental validation for the application of the flat jack test in cob walls. *Constr. Build. Mater.* **2020**, *254*, 119148. [CrossRef]
41. Quagliarini, E.; Maracchini, G. Experimental and FEM Investigation of Cob Walls under Compression. *Adv. Civ. Eng.* **2018**, *2018*, e7027432. [CrossRef]
42. Gunawardena, K.C. *The Future of Cob and Strawbale Construction in the UK*; University of Bath: Bath, UK, 2008.
43. Reilly, A.; Kinnane, O. The impact of thermal mass on building energy consumption. *Appl. Energy* **2017**, *198*, 108–121. [CrossRef]
44. Devon Earth Building Association. Cob Dwellings. 2008. Available online: https://www.devonearthbuilding.com/leaflets/building_regs_pamphlet_08.pdf (accessed on 23 March 2023).
45. Forest Research. Forestry Statistics 2019. Available online: https://cdn.forestresearch.gov.uk/2022/02/complete_fs2019.pdf (accessed on 23 March 2023).

46. Ridley-Ellis, D.; Moore, J.; Lyon, A.; Searles, G.; Gardiner, B. Strategic Integrated Research in Timber: Getting the most out of the UK's timber resource. *Non-Conv. Mater. Technol.* **2009**. Available online: https://www.napier.ac.uk/research-and-innovation/research-search/outputs/strategic-integrated-research-in-timber-getting-the-most-out-of-the-uks-timber (accessed on 10 January 2023).
47. Ashour, T.; Georg, H.; Wu, W. Performance of straw bale wall: A case of study. *Energy Build.* **2011**, *43*, 1960–1967. [CrossRef]
48. Garas, G.; Me, A.; El Dessuky, R. Straw Bale Construction as an Economic Environmental Building Alternative—A Case Study. *ARPN* **2009**, *4*, 54–59.
49. Steen, A.S. (Ed.) *The Straw Bale House*; Chelsea Green Pub. Co: White River Junction, VT, USA, 1994.
50. Goodhew, S.; Carfrae, J.; De Wilde, P. Briefing: Challenges related to straw bale construction. *Proc. Inst. Civ. Eng. Eng. Sustain.* **2010**, *163*, 185–189. [CrossRef]
51. US Department of Energy. House of Straw—Straw Bale Construction Comes of Age. 1995. Available online: https://www.doc-developpement-durable.org/file/Construction-Maisons_et_routes/MaisonsEnPailles/strawbalehouse.pdf (accessed on 23 March 2023).
52. Harries, K. *Nonconventional and Vernacular Construction Materials: Characterisation, Properties and Applications*, 2nd ed.; Woodhead Publishing: Sawston, UK, 2019.
53. Carfrae, J. *The Moisture Performance of Straw Bale Construction in a Temperate Maritime Climate*; University of Plymouth: Plymouth, UK, 2011. [CrossRef]
54. Hagman, O. A Technology in Permanent Transition: 200 Years of Cordwood Building with Consumers as Producers. *Icon* **2012**, *18*, 142–156.
55. ASPI Cordwood Buildings. 1990. Available online: http://www.appalachia-spi.org/uploads/1/3/4/9/13498092/tp5.pdf (accessed on 23 March 2023).
56. Ramage, M.H.; Burridge, H.; Busse-Wicher, M.; Fereday, G.; Reynolds, T.; Shah, D.U.; Wu, G.; Yu, L.; Fleming, P.; Densley-Tingley, D.; et al. The wood from the trees: The use of timber in construction. *Renew. Sustain. Energy Rev.* **2017**, *68*, 333–359. [CrossRef]
57. Mouterde, R.; Morel, J.C.; Martinet, V.; Sallet, F. The mechanical performance of cordwood. *Biosyst. Eng.* **2011**, *108*, 237–243. [CrossRef]
58. Martins, A.; Vasconcelos; Costa, C.A. Brick masonry veneer walls: An overview. *J. Build. Eng.* **2017**, *9*, 29–41. [CrossRef]
59. Yates, M.; Martin-Luengo, M.A.; Cornejo, J.; González, V. The Importance of the Porosity of Mortars, Tiles and Bricks in Relation to Their Bonding Strengths. In *Studies in Surface Science and Catalysis*; Elsevier: Amsterdam, The Netherlands, 1994; pp. 781–790.
60. Brown, P.W.; Clifton, J.R. Adobe. I. The Properties of Adobe. *Stud. Conserv.* **1978**, *23*, 139–146.
61. Quagliarini, E.; Lenci, S. The influence of natural stabilizers and natural fibres on the mechanical properties of ancient Roman adobe bricks. *J. Cult. Herit.* **2010**, *11*, 309–314. [CrossRef]
62. Acosta, J.D.R.; Diaz, A.G.; Zarazua, G.M.S.; Garcia, E.R. Adobe as a Sustainable Material: A Thermal Performance. *J. Appl. Sci.* **2010**, *10*, 2211–2216. [CrossRef]
63. Illampas, R.; Ioannou, I.; Charmpis, D.C. Adobe bricks under compression: Experimental investigation and derivation of stress–strain equation. *Constr. Build. Mater.* **2014**, *53*, 83–90. [CrossRef]
64. Pacheco-Torgal, F.; Lourenco, P.; Labrincha, J.; Chindaprasirt, P.; Kumar, S. (Eds.) *Eco-Efficient Masonry Bricks and Blocks*, 1st ed.; Woodhead Publishing: Oxford, UK, 2014.
65. Piani, T.L.; Weerheijm, J.; Peroni, M.; Koene, L.; Krabbenborg, D.; Solomos, G.; Sluys, L. Dynamic behaviour of adobe bricks in compression: The role of fibres and water content at various loading rates. *Constr. Build. Mater.* **2020**, *230*, 117038. [CrossRef]
66. Yang, Y.; Yu, S.Y.; Zhu, Y.; Shao, J. The Making of Fired Clay Bricks in China Some 5000 Years Ago. *Archaeometry* **2014**, *56*, 220–227. [CrossRef]
67. Stefanidou, M.; Papayianni, I.; Pachta, V. Analysis and characterization of Roman and Byzantine fired bricks from Greece. *Mater. Struct.* **2015**, *48*, 2251–2260. [CrossRef]
68. Klisińska-Kopacz, A.; Tišlova, R.; Adamski, G.; Kozłowski, R. Pore structure of historic and repair Roman cement mortars to establish their compatibility. *J. Cult. Herit.* **2010**, *11*, 404–410. [CrossRef]
69. Dan, M.B.; Přikryl, R.; Materials, T. *Technologies and Practice in Historic Heritage Structures*; Springer: Dordrecht, The Netherlands, 2010.
70. Johari, I.; Said, S.; Abu, B.; Bakar, B.H.; Ahmad, Z. Effect of the change of firing temperature on microstructure and physical properties of clay bricks from Beruas (Malaysia). *Sci. Sinter.* **2010**, *42*, 245–254. [CrossRef]
71. Ghiassi, B.; Lourenço, P.B. (Eds.) *Long-Term Performance and Durability of Masonry Structures*; Woodhead Publishing: Sawston, UK, 2018.
72. Brick Development Association. The UK Clay Brickmaking Process. 2023. Available online: https://www.brick.org.uk/uploads/downloads/09.-The-UK-Clay-Brickmaking-Process-General-Guide-2023.f1678701625.pdf (accessed on 23 March 2023).
73. Karaman, S.; Ersahin, S.; Gunal, H. Firing temperature and firing time influence on mechanical and physical properties of clay bricks. *J. Sci. Ind. Res.* **2006**, *65*, 153–159.
74. Brick Development Association. Designing to Brickwork Dimensions. 2023. Available online: https://www.brick.org.uk/uploads/downloads/04.-Designing-to-brickwork-dimensions-Techical-Guide-2023.f1678701338.pdf (accessed on 23 March 2023).
75. Mortar Industry Association. Brick and Block Production. 2013. Available online: https://www.mortar.org.uk/documents/LT05-Bricks-and-Blocks.pdf (accessed on 23 March 2023).

76. Shahreza, K.S.; Niklewski, J.; Molnár, M. Experimental investigation of water absorption and penetration in clay brick masonry under simulated uniform water spray exposure. *J. Build. Eng.* **2021**, *43*, 102583. [CrossRef]
77. Royal Institute of Chartered Surveyors. Modern Methods of Construction A Forward-Thinking Solution to the Housing Crisis? 2018. Available online: https://www.rics.org/content/dam/ricsglobal/documents/to-be-sorted/modern_methods_of_construction_paper_rics.pdf (accessed on 23 March 2023).
78. NHBC. NHBC Standards. 2021. Available online: https://nhbc-standards.co.uk/downloads/NHBC-Standards-2021-Complete.pdf (accessed on 23 March 2023).
79. Brick Industry Association. Fire Resistance of Brick Masonry. 2008. Available online: https://www.gobrick.com/docs/default-source/read-research-documents/technicalnotes/16-fire-resistance-of-brick-masonry.pdf (accessed on 23 March 2023).
80. Sutton, A.; Black, D.; Walker, P. *Building Research Establishment. Hemp Lime: An Introduction to Low-Impact Building Materials*; IHS BRE Press: Watford, UK, 2011.
81. Elfordy, S.; Lucas, F.; Tancret, F.; Scudeller, Y.; Goudet, L. Mechanical and thermal properties of lime and hemp concrete ("hempcrete") manufactured by a projection process. *Constr. Build. Mater.* **2008**, *22*, 2116–2123. [CrossRef]
82. Arrigoni, A.; Pelosato, R.; Melià, P.; Ruggieri, G.; Sabbadini, S.; Dotelli, G. Life cycle assessment of natural building materials: The role of carbonation, mixture components and transport in the environmental impacts of hempcrete blocks. *J. Clean. Prod.* **2017**, *149*, 1051–1061. [CrossRef]
83. Abdellatef, Y.; Khan, M.A.; Khan, A.; Alam, M.I.; Kavgic, M. Mechanical, Thermal, and Moisture Buffering Properties of Novel Insulating Hemp-Lime Composite Building Materials. *Material* **2020**, *13*, 5000. [CrossRef] [PubMed]
84. Collet, F.; Pretot, S. Thermal conductivity of hemp concretes: Variation with formulation, density and water content. *Constr. Build. Mater.* **2014**, *65*, 612–619. [CrossRef]
85. Wilson, P.L. Building with Scottish Stone. 2005. Available online: https://pub-prod-sdk.azurewebsites.net/api/file/745b1468-1ecf-413b-83e0-a59100f91470 (accessed on 23 March 2023).
86. Urquhart, D.; Scottish Stone Liaison Group. *Natural Stone Masonry in Modern Scottish Construction: A Guide for Designers and Constructors*; Scottish Stone Liaison Group: Charlestown, MA, USA, 2008.
87. Turkington, A.V.; Martin, E.; Viles, H.A.; Smith, B.J. Surface change and decay of sandstone samples exposed to a polluted urban atmosphere over a six-year period: Belfast, Northern Ireland. *Build. Environ.* **2003**, *38*, 1205–1216. [CrossRef]
88. Ruedrich, J.; Kirchner, D.; Siegesmund, S. Physical weathering of building stones induced by freeze–thaw action: A laboratory long-term study. *Envior. Earth Sci.* **2011**, *63*, 1573–1586. [CrossRef]
89. Song, R.; Zheng, L.; Wang, Y.; Liu, J. Effects of Pore Structure on Sandstone Mechanical Properties Based on Micro-CT Reconstruction Model. *Adv. Civ. Eng.* **2020**, *2020*, e9085045. [CrossRef]
90. Zorlu, K.; Gokceoglu, C.; Ocakoglu, F.; Nefeslioglu, H.A.; Acikalin, S. Prediction of uniaxial compressive strength of sandstones using petrography-based models. *Eng. Geol.* **2008**, *96*, 141–158. [CrossRef]
91. Baker, P. Technical Paper 10 U-Values and Traditional Buildings In Situ Measurements and their Comparisons to Calculated Values. 2011. Available online: https://pub-prod-sdk.azurewebsites.net/api/file/25a883fd-9a66-4cdd-9c5b-a67b01006f97 (accessed on 23 March 2023).
92. NHBC Foundation. Modern Methods of Construction. 2021. Available online: https://www.nhbcfoundation.org/wp-content/uploads/2021/01/MMC_report.pdf (accessed on 23 March 2023).
93. Office for National Statistics. UK House Building: Permanent Dwellings Started and Completed. Available online: https://www.ons.gov.uk/file?uri=/peoplepopulationandcommunity/housing/datasets/ukhousebuildingpermanentdwellingsstartedandcompleted/current/previous/v3/ukhousebuilding.xlsx (accessed on 23 March 2023).
94. Gagg, C.R. Cement and Concrete as an Engineering Material: An Historic Appraisal and Case Study Analysis. *Eng. Fail. Anal.* **2014**, *40*, 114–140. [CrossRef]
95. The Constructor. What is a Cavity Wall? Construction and Advantages of Cavity Walls. Available online: https://theconstructor.org/structural-engg/cavity-walls-construction-advantages/14000/ (accessed on 23 March 2023).
96. Kariyawasam, K.; Jayasinghe, C. Cement stabilized rammed earth as a sustainable construction material. *Constr. Build. Mater.* **2016**, *105*, 519–527. [CrossRef]
97. Zare, P.; Narani, S.S.; Abbaspour, M.; Fahimifar, A.; Hosseini, S.M.M.M.; Zare, P. Experimental investigation of non-stabilized and cement-stabilized rammed earth reinforcement by Waste Tire Textile Fibers (WTTFs). *Constr. Build. Mater.* **2020**, *260*, 120432. [CrossRef]
98. Guettala, A.; Abibsi, A.; Houari, H. Durability study of stabilized earth concrete under both laboratory and climatic conditions exposure. *Constr. Build. Mater.* **2006**, *20*, 119–127. [CrossRef]
99. HM Government. Approved Document C Site Preparation and Resistance to Contaminants and Moisture. 2010. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/431943/BR_PDF_AD_C_2013.pdf (accessed on 23 March 2023).
100. Damms, H.; Djerbib, Y. Stabilised Rammed Earth—Physical Properties and Compliance with UK Building Regulations. 2004. Available online: http://www.earthstructures.co.uk/SREregcompliance.pdf (accessed on 23 March 2023).
101. The Australian Institute of Refrigeration, Air Conditioning and Heating. *AIRAH Technical Handbook*; AIRAH: Brisbane, Australia, 2000.

102. Allinson, D.; Hall, M. Hygrothermal analysis of a stabilised rammed earth test building in the UK. *Energy Build.* **2010**, *42*, 845–852. [CrossRef]
103. Indekeu, M.; Woloszyn, M.; Grillet, A.C.; Soudani, L.; Fabbri, A. Towards hygrothermal characterization of rammed earth with small-scale dynamic methods. *Energy Procedia* **2017**, *132*, 297–302. [CrossRef]
104. Adam, E.A.; Jones, P.J. Thermophysical properties of stabilised soil building blocks. *Build. Environ.* **1995**, *30*, 245–253. [CrossRef]
105. *BS EN 12390-1*; Testing Hardened Concrete—Shape, Dimensions and Other Requirements for Specimens and Moulds. British Standards Institute: Loughborough, UK, 2021. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
106. *BS EN 206*; Concrete—Specification, Performance, Production and Conformity. British Standards Institute: Loughborough, UK, 2016. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
107. *BS 8500-1*; Concrete. Complementary British Standard to BS EN 206 Method of Specifying and Guidance for the Specifier . British Standards Institute: Loughborough, UK, 2019. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
108. Green, W.K. Steel reinforcement corrosion in concrete—An overview of some fundamentals. *Corros. Eng. Sci. Technol.* **2020**, *55*, 289–302. [CrossRef]
109. Princy, K.P.; Elson, J. Study on the Effectiveness of Various Curing Methods on the Properties of Concrete. *Int. J. Eng. Res. Technol.* **2015**, *4*, 213–216. [CrossRef]
110. O'Hegarty, R.; Kinnane, O. Review of precast concrete sandwich panels and their innovations. *Constr. Build. Mater.* **2020**, *233*, 117145. [CrossRef]
111. Zhang, J.; Liu, G.; Chen, B.; Song, D.; Qi, J.; Liu, X. Analysis of CO_2 Emission for the Cement Manufacturing with Alternative Raw Materials: A LCA-based Framework. *Energy Procedia* **2014**, *61*, 2541–2545. [CrossRef]
112. MPA British Precast. Sustainability Matters 2020 Sustainability Performance Report (2019 Data). 2020. Available online: https://www.mpaprecast.org/getattachment/Sustainability/Sustainability-Report/Sustainability-Matters-2020-(FINAL).pdf.aspx (accessed on 23 March 2023).
113. The Concrete Centre. Hybrid Concrete Construction—Maximising the Potential of Concrete by Combining Precast and In-Situ Concrete. 2010. Available online: https://www.concretecentre.com/Resources/Publications/Hybrid-Concrete-Construction.aspx (accessed on 23 March 2023).
114. Aouad, G.; Barrett, P. The Feasibility of Using Hybrid Concrete Structures within the Context of Cost and Time. Available online: https://www.arcom.ac.uk/-docs/proceedings/ar1998-155-164_Aouad_and_Barrett.pdf (accessed on 23 March 2023).
115. Tavafoghi, A.; Eshghi, S. Evaluation of behavior factor of tunnel-form concrete building structures using Applied Technology Council 63 methodology: Behavior Factor of Tunnel-form Concrete Building Structures. *Struct. Des. Tall Spec. Build.* **2013**, *22*, 615–634. [CrossRef]
116. The Concrete Centre. Tunnel Form. Available online: https://www.concretecentre.com/Building-Solutions/Walls/Tunnel-form.aspx (accessed on 23 March 2023).
117. Kalkan, E.; Yüksel, S.B. Pros and cons of multistory RC tunnel-form (box-type) buildings. *Struct. Des. Tall Spec. Build.* **2008**, *17*, 601–617. [CrossRef]
118. Gasparini, D.A. Contribution of C.A.P. Turner to the Development of Reinforced Concrete Flat Slabs 1905–1909. Available online: https://engineering.case.edu/eciv/sites/engineering.case.edu.eciv/files/CAPTurner.pdf. (accessed on 23 March 2023).
119. The Institute of Structural Engineers. Floor Slab Construction 2013. Available online: https://www.istructe.org/journal/volumes/volume-91-(2013)/issue-9/technical-guidance-note-floor-slab-construction/ (accessed on 23 March 2023).
120. Hashem, M.; Hassan, H.; Willim, W.; Gamal, K. Behavior of Flat Slab With Drop Area or Varying thickness. *Egypt. J. Eng. Sci. Technol.* **2019**, *28*, 1–8. [CrossRef]
121. Joohari, I.B.; Amin, N.B.M. Development of Flat Slab—Column Interaction with Different Thickness. *MATEC Web Conf.* **2017**, *97*, 1038. [CrossRef]
122. Faria, D.M.V.; Einpaul, J.; Ramos, A.M.P.; Ruiz, M.F.; Muttoni, A. On the efficiency of flat slabs strengthening against punching using externally bonded fibre reinforced polymers. *Constr. Build. Mater.* **2014**, *73*, 366–377. [CrossRef]
123. UNECE. Unece Timber Forecast—September 2016. Available online: https://unece.org/DAM/timber/country-info/statements/UK2016.pdf (accessed on 23 March 2023).
124. Taylor, S. Offsite Production in the UK Construction Industry—A Brief Overview. Available online: https://www.buildoffsite.com/content/uploads/2015/04/HSE-off-site_production_june09.pdf (accessed on 23 March 2023).
125. Hairstans, R. Building Offsite. 2014. Available online: https://www.cs-ic.org/media/1291/building_offsite_an_introductioncompressed.pdf (accessed on 12 March 2023).
126. NHBC Foundation. Modern Methods of Construction Views from the Industry. 2016. Available online: https://www.nhbcfoundation.org/wp-content/uploads/2016/07/NF70-Modern-methods-of-construction.pdf (accessed on 23 March 2023).
127. Amran, Y.M.; El-Zeadani, M.; Lee, Y.H.; Lee, Y.Y.; Murali, G.; Feduik, R. Design innovation, efficiency and applications of structural insulated panels: A review. *Structures* **2020**, *27*, 1358–1379. [CrossRef]
128. Panjehpour, M.; Ali, A.; Voo; Panels, Y.S.I. Present, and Future. *J. Eng. Proj. Prod. Manag.* **2013**, *3*, 2–8.

129. *BS EN 14081-1*; Timber Structures. Strength Graded Structural Timber with Rectangular Cross Section General Requirements. British Standards Institute: Loughborough, UK, 2019. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
130. Yusoh, A.S.; Tahir, P.; Uyup, M.K.A.; Lee, S.H.; Husain, H.; Khaidzir, M.O. Effect of wood species, clamping pressure and glue spread rate on the bonding properties of cross-laminated timber (CLT) manufactured from tropical hardwoods. *Constr. Build. Mater.* **2021**, *273*, 121721. [CrossRef]
131. Chang, S.J.; Wi, S.; Kim, S. Thermal bridging analysis of connections in cross-laminated timber buildings based on ISO 10211. *Constr. Build. Mater.* **2019**, *213*, 709–722. [CrossRef]
132. Gardner, C.; Davids, W.G.; Lopez-Anido, R.; Herzog, B.; Edgar, R.; Nagy, E.; Berube, K.; Shaler, S. The effect of edge gaps on shear strength and rolling shear modulus of cross laminated timber panels. *Constr. Build. Mater.* **2020**, *259*, 119710. [CrossRef]
133. Stora Enso. CLT—Technical Brochure. 2013. Available online: https://www.storaenso.com/-/media/documents/download-center/documents/product-brochures/wood-products/clt-by-stora-enso-technical-brochure-en.pdf (accessed on 23 March 2023).
134. Kippel, M.; Leyder, C.; Frangi, A.; Fontana, M. Fire Tests on Loaded Cross-laminated Timber Wall and Floor Elements. *Fire Saf. Sci.* **2014**, *11*, 626–639. [CrossRef]
135. Frangi, A.; Bochicchio, G.; Ceccotti, A.; Lauriola, M.P. Natural Full-Scale Fire Test on a 3 Storey XLam Timber Building. In Proceedings of the 10th World Conference on Timber Engineering 2008, Miyazaki, Japan, 2–5 June 2008; Volume 1, pp. 528–535.
136. Crawford, D.; Hairstans, R.; Smith, S.; Papastavrou, P. Viability of cross-laminated timber from UK resources. *Proc. Inst. Civ. Eng. Constr. Mater.* **2015**, *168*, 110–120. [CrossRef]
137. Lawson, R.M.; Ogden, R.; Goodier, C.I. *Design in Modular Construction*, 1st ed.; CRC Press: London, UK, 2014.
138. NHBC Foundation. Modern Methods of Construction—Who's Doing What? 2018. Available online: https://www.nhbcfoundation.org/wp-content/uploads/2018/11/NF82.pdf (accessed on 24 March 2023).
139. Building (Scotland) Act 1959. Available online: https://www.legislation.gov.uk/ukpga/Eliz2/7-8/24/enacted (accessed on 23 March 2023).
140. The Building Operations (Scotland) Regulations 1963. Available online: https://era.ed.ac.uk/bitstream/handle/1842/5114/A6%20SI%201959%20The%20Building%20Operations%20%28Scotland%29%20Regulations%201963.pdf (accessed on 23 March 2023).
141. Public Health Act 1961. Available online: https://www.legislation.gov.uk/ukpga/Eliz2/9-10/64/contents (accessed on 23 March 2023).
142. The Building Regulations 1965. Available online: https://www.legislation.gov.uk/uksi/1965/1373/pdfs/uksi_19651373_en.pdf (accessed on 23 March 2023).
143. Slater, T.R.; Pinto, S.M.G. (Eds.) *Building Regulations and Urban Form, 1200–1900*; Routledge: New York, UK, 2018.
144. The London Building Act. 1930. Available online: https://www.legislation.gov.uk/ukla/1930/158/pdfs/ukla_19300158_en.pdf (accessed on 23 March 2023).
145. Building Act. 1984. Available online: https://www.legislation.gov.uk/ukpga/1984/55 (accessed on 23 March 2023).
146. Building (Scotland) Act. 2003. Available online: https://www.legislation.gov.uk/asp/2003/8/contents (accessed on 23 March 2023).
147. The Building (Scotland) Regulations. 2004. Available online: https://www.legislation.gov.uk/ssi/2004/406/schedule/5/made (accessed on 23 March 2023).
148. The Building Regulations. 2010. Available online: https://www.legislation.gov.uk/uksi/2010/2214/contents (accessed on 23 March 2023).
149. UK Government. Changes to Legislation. Available online: https://www.legislation.gov.uk/changes?affected-title=building%20regulations%202010&results-count=50&sort=affecting-year-number&order=descending&page=1 (accessed on 12 March 2023).
150. UK Government. Changes to Legislation—Scotland. Available online: https://www.legislation.gov.uk/changes?affected-title=building%20regulations%20scotland%202004 (accessed on 10 March 2023).
151. Government of Wales Act 2006. Available online: https://www.legislation.gov.uk/ukpga/2006/32/contents (accessed on 23 March 2023).
152. The Welsh Ministers (Transfer of Functions) (No. 2) Order 2009. Available online: https://www.legislation.gov.uk/uksi/2009/3019/made (accessed on 12 March 2023).
153. Scottish Government. Technical Handbook—Domestic. 2020. Available online: https://www.gov.scot/binaries/content/documents/govscot/publications/advice-and-guidance/2021/02/building-standards-technical-handbook-2020-domestic/documents/building-standards-technical-handbook-2020-domestic/building-standards-technical-handbook-2020-domestic/govscot%3Adocument/Building%2BStandards%2B-%2Bpublications%2B-%2Btechnical%2Bhandbook%2B-%2Bdomestic%2B-%2Bapril%2B2021.pdf (accessed on 12 March 2023).
154. HM Government. Approved Document M Access to and Use of Buildings. 2016. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/540330/BR_PDF_AD_M1_2015_with_2016_amendments_V3.pdf (accessed on 23 March 2023).
155. Welsh Government. Approved Document Part M (Access to and Use of Buildings). 2010. Available online: https://gov.wales/sites/default/files/publications/2019-05/building-regulations-guidance-part-m-access-to-and-use-of-buildings.pdf (accessed on 23 March 2023).

156. HM Government. Approved Document L1a Conservation of Fuel and Power in New Dwellings. 2016. Available online: https://webarchive.nationalarchives.gov.uk/ukgwa/20190213060753/https:/www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l (accessed on 12 March 2023).
157. HM Government. Approved Document A Structure. 2013. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/429060/BR_PDF_AD_A_2013.pdf (accessed on 20 March 2023).
158. Welsh Government. Approved Document Part A (Structural Safety). 2010. Available online: https://gov.wales/sites/default/files/publications/2019-04/170403building-regs-approved-document-a-structure-en.pdf (accessed on 23 March 2023).
159. Welsh Government. Approved Document Part C (Site Preparation and Resistance to Contaminants and Moisture). 2010. Available online: https://gov.wales/sites/default/files/publications/2019-05/building-regulations-guidance-part-c-resistance-to-contaminants-and-moisture.pdf (accessed on 23 March 2023).
160. HM Government. Approved Document H Drainage and Waste Disposal. 2015. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/442889/BR_PDF_AD_H_2015.pdf (accessed on 23 March 2023).
161. Welsh Government. Approved Document: Part H (Drainage and Waste Disposal). Available online: https://gov.wales/sites/default/files/publications/2019-05/building-regulations-guidance-part-h-drainage-and-waste-disposal.pdf (accessed on 23 March 2023).
162. The Natural Resources Body for Wales (Functions) Order 2013. Available online: https://www.legislation.gov.uk/wsi/2013/755/made (accessed on 23 March 2023).
163. *BS EN 13501-2*; Fire Classification of Construction Products and Building Elements. Classification Using Data from Fire Resistance Tests, excluding Ventilation Services. British Standards Institute: Loughborough, UK, 2016. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
164. HM Government. Approved Document B Fire Safety. 2020. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/937931/ADB_Vol1_Dwellings_2019_edition_inc_2020_amendments.pdf (accessed on 23 March 2023).
165. Welsh Government. Approved Document Part B Fire Safety (Dwellinghouses). 2020. Available online: https://www.gov.wales/sites/default/files/publications/2021-12/building-regulations-guidance-part-b-fire-safety-volume-1-dwellinghouses.pdf (accessed on 23 March 2023).
166. Welsh Government. Approved Document Part B Fire Safety (Other than Dwellinghouses). 2020. Available online: https://www.gov.wales/sites/default/files/publications/2021-12/building-regulations-guidance-part-b-fire-safety-volume-2-buildings-other-than-dwellinghouses.pdf (accessed on 23 March 2023).
167. *BS 476-3*; Fire Tests on Building Materials and Structures—Classification and Method of Test for External Fire Exposure to Roofs. British Standards Institute: Loughborough, UK, 2004. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
168. *BS EN 13501-5*; Fire Classification of Construction Products And Building Elements—Part 5: Classification Using Data from External Fire Exposure to Roofs Tests. British Standards Institute: Loughborough, UK, 2016. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
169. HM Government. Approved Document E Resistance to the Passage of Sound. 2015. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/468870/ADE_LOCKED.pdf (accessed on 23 March 2023).
170. Welsh Government. Approved Document Part E (Resistance to the Passage of Sound). 2010. Available online: https://gov.wales/sites/default/files/publications/2019-05/building-regulations-guidance-part-e-resistance-to-the-passage-of-sound.pdf (accessed on 23 March 2023).
171. *BS EN ISO 717-1*; Acoustics—Rating of Sound Insulation in Buildings and of Building Elements—Part 1: Airborne Sound Insulation. British Standards Institute: Loughborough, UK, 2021. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
172. Rasmussen, B.; Rindel, J. Concepts for evaluation of sound insulation of dwellings—From chaos to consensus? In Proceedings of the Forum Acusticum, Budapest, Hungary, 29 August–2 September 2005.
173. Welsh Government. Approved Document Part L1a (Conservation of Fuel and Power in New Dwellings). 2016. Available online: https://www.gov.wales/sites/default/files/publications/2019-05/building-regulations-guidance-part-l-conservation-of-fuel-and-power-2014-l1a-new-dwellings.pdf (accessed on 23 March 2023).
174. The Building (Scotland) Amendment Regulations. 2011. Available online: https://www.legislation.gov.uk/ssi/2011/120/made (accessed on 12 March 2023).
175. *BS EN ISO 10456*; Building Materials and Products—Hygrothermal Properties—Tabulated Design Values and Procedures for Determining Declared and Design Thermal Values. British Standards Institute: Loughborough, UK, 2010. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
176. Giada, G.; Caponetto, R.; Nocera, F. Hygrothermal Properties of Raw Earth Materials: A Literature Review. *Sustainability* **2019**, *11*, 5342. [CrossRef]
177. Maniatidis, V.; Walker, P. A Review of Rammed Earth Construction. 2003. Available online: https://people.bath.ac.uk/abspw/rammedearth/review.pdf (accessed on 23 March 2023).

178. Rye, C.; Scott, C. The SPAB Research Report 1: U-Value Report. 2012. Available online: https://www.spab.org.uk/sites/default/files/documents/MainSociety/Advice/SPABU-valueReport.Nov2012.v2.pdf (accessed on 23 March 2023).
179. Costes, J.-P.; Evrard, A.; Biot, B.; Keutgen, G.; Daras, A.; Dubois, S.; Lebeau, F.; Courard, L. Thermal Conductivity of Straw Bales: Full Size Measurements Considering the Direction of the Heat Flow. *Buildings* **2017**, *7*, 11. [CrossRef]
180. Shafigh, P.; Asadi, I.; Akhiani, A.R.; Mahyuddin, N.B.; Hashemi, M. Thermal properties of cement mortar with different mix proportions. *Mater. Construcc.* **2020**, *70*, 224. [CrossRef]
181. Quentin, W.; Higbee-Barzola, K.; Friedman, G. When Thermal Mass Becomes Resistance. 2016. Available online: https://www.theearthbuildersguild.com/_files/ugd/56012a_e398f6de1c024ba3bdae26dfc616d3c9.pdf (accessed on 23 March 2023).
182. Anderson, B.; Kosmina, L. Conventions for U-Value Calculations. 2019. Available online: https://www.bregroup.com/wp-content/uploads/2019/10/BR443-October-2019_consult.pdf (accessed on 23 March 2023).
183. Structural Timber Association. Cross-Laminated Timber Construction—An Introduction. Technical Bulletin 11. 2015. Available online: https://www.structuraltimber.co.uk/libraries/technical-documents/ (accessed on 23 March 2023).
184. Švajlenka, J.; Kozlovská, M.; Badida, M.; Moravec, M.; Dzuro, T.; Vranay, F. Analysis of the Characteristics of External Walls of Wooden Prefab Cross Laminated Timber. *Energies* **2020**, *13*, 5974. [CrossRef]
185. *ENV 1187*; Test Methods for External Fire Exposure to Roofs. British Standards Institute: Loughborough, UK, 2002. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).
186. *BS EN ISO 6946*; Building Components and Building Elements—Thermal Resistance and Thermal Transmittance—Calculation Methods. British Standards Institute: Loughborough, UK, 2017. Available online: https://www.bsigroup.com/en-GB/standards/ (accessed on 23 March 2023).