Natural and Regionally Available Materials for a Sustainable Future _
Reviving Tradition in Contemporary Construction

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ABSTRACT **Energy issues, environmental impact and circularity are key words in the building industry today. Recent practice introduced many artificial materials, regardless of their origin, impact on health, local economy, or life cycle characteristics. Increased resource consumption and carbon dioxide emission, on the one hand, and waste generation on the other hand, have caused significant environmental problems. The globalisation of the building materials market, the huge amounts of energy used for their mass production and transportation, and the inclination away from traditional materials and crafts caused the building industry to become a major environmental polluter.**

There is great potential for renewable, natural and locally grown, and extracted and manufactured materials all over Europe. Before the wars of the 1990s, the building industry in ex-Yugoslav countries relied on "Krivaja", "Šipad", "Marles" and other manufacturing companies that fully based their programmes on renewable materials from local sources, and on know-hows about traditional crafts. Nowadays, by focusing on the performance of building materials, new environmentally friendly technologies, and new approaches to traditional buildings and settlements, architects, designers, and engineers are challenged to create a new sustainable and resilient environment.

This chapter will introduce traditional, natural, locally produced and recyclable materials – wood, stone, clay, and alternative natural and regionally available materials – sheep wool and straw, as potentials to develop new building practices, keep old crafts alive, boost local economy, improve health, and decrease negative impacts on the living environment.

KEYWORDS natural materials, stone, wood, clay, alternative materials

1 Introduction

Along with their first intentions to settle in a certain location, humans started to explore the ways of using locally available materials for building shelters. Wood, stone, clay, animal skin, and different plants offered many possibilities, and so prehistoric man started to experiment, with the aim of finding the best solution for his micro-location.

From the end of the 18th century, global ecological picture started to change rapidly. The Industrial Revolution fomented the development of new manufacturing technologies. Available technologies introduced new materials, or improved the quality of existing ones. Developed transportation took on a significant role in various processes, from the delivery of raw materials, final product distribution, to the flow of working labour. During the 20th century, houses became machines, equipped with cables, pipes, elevators, heating systems, and other sophisticated technologies.

The increased consumption of all natural goods, utilisation of artificial substances, and developed transportation jeopardised the quality of living environments, and made buildings and cities among the most significant consumers and polluters.

By learning from traditional architecture, carefully considering the life cycle of materials and buildings, cultivating traditional skills and encouraging circular economy, it is possible to improve the quality of life and of environment, boost local economy and tourism, and create trends with developed countries and their agendas for sustainable and resilient future (Roso Popovac, Šahinagić-Isović, Šarančić-Logo, & Ćećez, 2017).

Natural and regionally available materials are the optimal choice for contemporary sustainable and efficient construction. These materials do not require complex processing or long transportation, and may later be easily re-used, recycled, or left to decompose, without harmful impact on the environment. Traditionally, natural materials were used in the best possible way: they were adaptive to the site, climate, needs and opportunities, and developed through the adequate crafts and architectural techniques.

Research carried out in Libya has showed that 600-year-old houses, when the outside temperature is around 44°C, maintain an average inside temperature of 26°C, compared to 38°C in new non-air-conditioned houses (Kamal & Al Shehab, 2014). When coupled with traditional techniques like passive cooling, traditional materials sustain indoor comfort for many years and, for that reason, are continuously used in different parts of the world.

In contrast to the artificial, natural materials generally have better attributes when it comes to human health considerations, not only in the phase of use and maintenance, but throughout the whole life cycle. For example, natural (and naturally treated) wood has been proven to be an exceptionally healthy building material. However, it is also true that natural products originating from the ground can possibly contain measurable amounts of radiation. Stone, minerals, sand, and clay all may have the trace amounts of radioactive elements commonly called the NORMs (Naturally Occurring Radioactive Minerals). Nonetheless, the most significant sources of radiation are not materials, but the ground soils.

At the end of service life, natural materials may be re-used, recycled, or biologically decomposed. For example, wood material and components may be reused in another building or recycled into a source of thermal energy. Previously used wool and straw can be reused in agriculture to keep the moisture around the plants. Today, there are many interesting initiatives and projects for circular design and recycling of existing materials, among them the EU funded project *BAMB* (Buildings as Material Banks) which aims to develop the strategy for eliminating construction waste and to link material circularity with a circular economy. Another example is the *Harvest map* (https://www.harvestmap.org), a marketplace for professional 'upcyclers'' from the Netherlands, i.e. a platform for easy, accessible trade with previously used materials of different kinds.

To intensify the utilisation of natural and regionally available materials, local community and stakeholders need wider knowledge, more information, and a positive attitude. After the introduction and spread of the use of artificial materials over the last 50 years, a lot of effort is now needed to break prejudices like 'wood is not fire-resistant', 'straw is going to provide shelter to rodents and insects', 'sheep wool has a bad smell', among others. As the price of natural materials is often slightly higher in comparison to conventional materials, the economically driven decisions of investors with regard to initial investment should be re-defined to support their application.

This chapter reviews several most common natural and regionally available building materials: stone, wood, and clay. Environmental qualities, traditional application, and possibilities for utilisation of these materials in contemporary terms are analysed, and the examples, followed by an adequate argument, are presented. The work also considers some alternative natural and regionally available materials whose utilisation today could be intensified.

2 Stone

In past times, stone material was used for load-bearing constructions. Typically, thick stone walls in traditional multi-storey buildings mainly consisted of two outside layers of masonry work with crushed stone and mortar infills. Although the construction process was generally slow and demanded masonry skills, the structural stability, regenerative powers of lime mortar, and easy rebuilding and reconstruction gave 'eternal life' to many stone structures.

The Balkan region is rich with various stone types. Some Balkan quarries were the sources of material for ancient Greek and Roman settlements along the coast and islands of the Adriatic Sea, and in inland areas. Among the best-known quarries of that time were Istria, Pućišta on Brač island, Mukoša near Mostar, and Jablanica.

The stone structures are durable, reusable, and recyclable. In fact, stone is one of the few building materials that rarely demands any additional processing after the extraction (at the beginning of the life cycle) and remodelling of its original size and shape (before first and every subsequent installation).

The examples of reuse of stone material previously incorporated into other built structures are numerous and various. Sometimes, ready-to-use building material was found at the location where an original building had previously existed. In other cases, the demolition of original stone structures was related to the symbolic demonstration of domination of new conquerors over a previous culture. In these circumstances, previously used material was often incorporated into the foundations of new structure.

The traces of Roman basilicas, temples, and other obsolete building types may be found in existing structures throughout Europe and Asia (Fig. 2.1).

FIG. 2.1 Cathedral in Pula made of stone from Roman temple

FIG. 2.2 Stone blocks from Austro-Hungarian fortification incorporated into fence wall, Mostar

In ex-Yugoslav countries, many built cultural-historic monuments were destroyed during the wars of the 1990s. Due to the lack of awareness about the value of cultural heritage (Roso Popovac, 2015), the purpose of devastation in some cases was no greater than to supply the stone blocks. The parts of stone bridges, fortifications, houses, and sacral objects were so embedded into new structures that they left no trace of their existence at the original location (Fig. 2.2).

Although stone belongs to the group of materials with low health hazards for users, its extraction and processing can jeopardise workers' health with some serious conditions like pneumoconiosis or dermatoses. Stone dust can contain iron, zinc, cadmium, nickel, lead, chromium, barium, beryllium, and aluminium (Ugbogu, Ohakwe, & Foltescu, 2009). However, the impact generated with stone extraction is in contrast with its potential for continual re-use and re-cycling.

With technological advancement, stone processing is transforming into an automatised process, providing a huge scale of products of different sizes and shapes. Stone processing and adjustment do not generate waste material, because even the smallest particles can be used (as gravel, for artificial stone or concrete production, etc.).

The main constraints related to stone utilisation are its price, which can exceed the price of other building materials by several times, the costs for skilled workers, and the duration of construction works. Nevertheless, quality, durability, and other performance characteristics justify the increment of initial investment.

Nature provides three types of stone:

- **Volcanic (Igneous)**, made mainly of magma that cools under the surface, with crystallised mineral gasses that cause crystalline formations (e.g. granite and basalt);
- **Sedimentary**, where sediments of organic particles from glaciers, rivers, plants, wind, and soil together form the stone under pressure, heat, and other conditions (e.g. limestone, sandstone, travertine);
- **Metamorphic** mixture of various existing natural stone types formed by exposure to pressure, heat, and minerals (such as marble, serpentine).

Stone types are often named after the location in which they are found. A typical example is the famous *Carrara marble*, a light grey-blue stone of excellent quality. Many famous ancient and contemporary buildings like the Pantheon, Trajan's Column, the Peace Monument in Washington D.C., as well as the Michelangelo's famous sculpture David, and many others, were made of Carrara marble. The old bridge of Mostar is made from *Tenelija* limestone found only in Mukoša quarry near Mostar in Bosnia and Herzegovina. Another famous limestone, so called *Bath stone,* has been used in many buildings throughout South England.

Although stone has been used in on-site terrazzo floor production for decades, a fourth, prefabricated type, man-made or engineered stone, is available on the market today. With its price and availability, artificial stone is a great competitor of natural stone types. It is obtained mainly from marble and quartz (over 93-97%) with the addition of polymer resin (lately, of popular geopolymer).

When it comes to stone selection, its specific purpose, type of structure, and climate conditions need to be considered. For example, porous stone laid horizontally in exterior construction can cause additional loads that influence construction stability and result in a spectre of damages, leading to deterioration, and finally destruction.

Stone is also one of the most widely used raw materials in the world. It is used in production of lime, cement, man-made stone, concrete, and other artificial materials. As the requirements for improvement of stone characteristics are becoming increasingly demanding, the number of chemical agents involved in production, maintenance and preservation of stone, from slip and fire protection coats to nanotechnologies in monument protection, are growing. Some of these materials can, however, lower the ecological quality of natural stone. Chemical treatment can be a source of harmful substances for humans and nature, and might not provide the same bonding for different materials (for example in production of concrete), which influences the quality of final product.

When it comes to radiation issues, one of the most notorious stone types is granite. Nevertheless, the general claim regarding the radioactivity of stone is very vague, having regarded that the concentrations of radioactive elements depend on the location from which the stone material was taken, and that they vary from one sample to another, or even within the same stone element.

2.1 Stone in Contemporary Design

One of the most interesting contemporary examples of stone utilisation in Bosnia and Herzegovina is the estate of six homes in Bijača village, owned by the Stanić family. Design studio "2 Arhitekta" (Tomislav Ćurković and Zoran Zidarić) developed the project that combines traditional materials, shapes, and forms through modern architectural expression.

A

B

FIG. 2.3 A+B: Stanić family house in Bijača

The houses are made of traditional stone visible on the façade, with a 50cm wide stone trim and oversized asymmetric concrete window frames, which are reminiscent of the old houses and their white stone window frames. The material used for these structures is typical, local limestone cut in blocks, and the masonry work revives the traditional way of local building.

TOC

The entire property is covered with vineyards and green plots supported with a kilometres-long drywall, a typical stone structure in Herzegovina, Istria, Dalmatia, and other karst areas. Traditionally, there were three main reasons for building the drywalls. The first was to provide the boundary between different owners' plots and a protective barrier to animals and intruders. The second reason was to create plots with level ground on steep terrain, whereby the drywall was used as a support structure. The third reason was to clear the plot of stones, as people were trying to increase the area of fertile soil for their gardens by day-to-day stone collection.

The entire complex in the village of Bijača was built in one year. The construction process was, in fact, a perfect workshop for young stone cutters who practiced and learned old crafts. Because of the chosen materials, orientation, and knowledge from the past, the durability of the complex in Bijača will undoubtedly exceed the houses made of contemporary materials.

2.2 Lime

Besides its most common use as a building block, stone can be used as sticking and adhering material – component of lime mortar.

Hydraulic lime is a traditional building material that was used for thousands of years by Egyptians, Greeks, Romans, and other ancient cultures. Traditionally, lime is not only used as a component of mortar, but also as a plastering and coating material. Until recently, lime was the main material used as a disinfectant for annual indoor and outdoor wall painting, water purification, fruit trees painting to prevent sun scald, toilet space sanitisation, etc. For these reasons, it was common in ex-Yugoslav countries to have a pit in the household yard, in which lime was hydrated for generations.

Buildings constructed before 1920 were mostly made with hydraulic or hydrated lime. Today, lime is mostly used as an addition to cement mortars, for reconstruction of historical buildings and monuments, and for production of ready-to-use mortars. Due to the use of artificial paints and chemicals against insects and for disinfection, lime is very rarely used nowadays. The tradition of burning lime is still alive, but significantly reduced due to the industrial production of powdered lime for mortars. As the awareness about the healthy living environment is (re)entering ex-Yugoslav countries, together with the revival of traditional techniques, it is possible that the demands for natural lime will increase in future.

In the European Standard EN 459-1:2015, lime is defined as: "calcium oxide and/or hydroxide, and calcium-magnesium oxide and/or hydroxide produced by the thermal decomposition (calcination) of naturally occurring calcium carbonate (for example limestone, chalk, shells) or naturally occurring calcium magnesium carbonate (for example dolomitic limestone, dolomite)". Same standard (EN 459-1:2015) introduces two families of lime: "air lime and lime with hydraulic properties, used in applications or materials for construction, building and civil engineering."

3 Wood

Wood is the ultimate renewable material. It possesses qualities that have made it a material of choice for millennia, and these qualities are further enhanced by its recognised ability to sequestrate carbon, while the polymeric components of wood and its porous structure confer on it a noble, versatile, and general-purpose character and a faculty for transformation exceeding that of all other materials. Trees and their derivative products, nowadays known as engineered wood products, have been used around the world for thousands of years. The contemporary construction of tall buildings has recently been particularly challenged with the potential use of timber as a major structural element (Ramage et al., 2017). The unique advantages of this material, its widespread availability, sustainable renewal, favourable ecological performance, and flexibility of implementation grant it a status of "nobility" in the eyes of scientists and engineers. In the eyes of architects, however, the simplicity and beauty of wood as a new aesthetic are not just visual experiences - architects even try to integrate the smell, texture, and tangibility of wood into the architectural built environment. Forests and timber are a unique ecological value chain with great potential for future uses.

The specificities of a natural and sustainable material from a local forest should be seen as a starting point for the new approaches to contemporary products that suit individual building types and are in harmony with regional building culture. Basic traditional architectural principles, linked with the economic position of each country, influence the development of sustainable contemporary architecture and new methodologies.

3.1 Cascade Use of Wood for Sustainability

Cascading is a strategy of using raw materials such as wood or other bio-based materials in chronologically sequential steps, as efficiently as possible, for new materials, or to recover energy when it no longer is economical or technically possible to renew the use (Fig. 3.1). The use of the same unit of wood for multiple successive applications will result in a gradual reduction of quality and particle size (Meier, Streiff, Richter, & Sell, 1990).

In the forest products industry, waste hierarchy is presently underdeveloped and largely ignores the EU's preferred option of maximising the carbon storage potential of wooden materials through their reuse in solid form with the subsequent downcycling of reclaimed wood, in as many steps of a material cascade as possible (Leek, 2010).

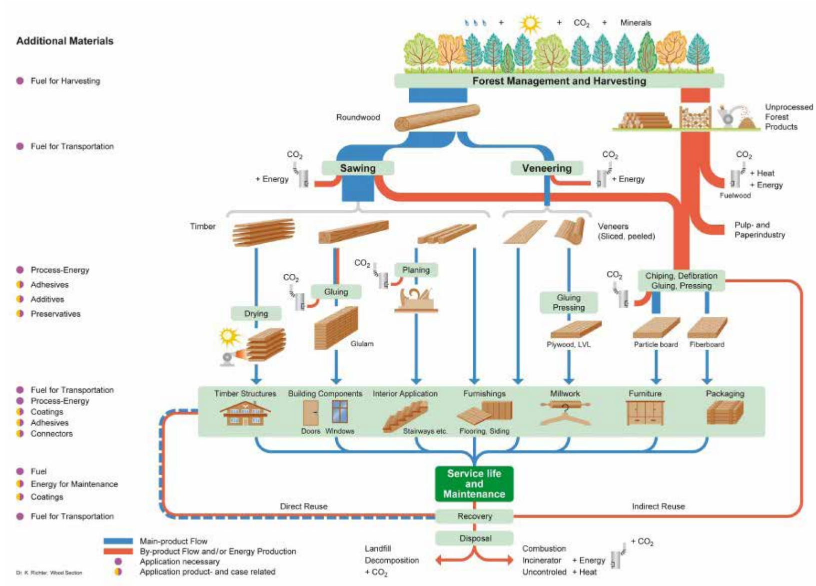

FIG. 3.1 Cascade use of wood *(Meier et al., 1990)*

3.2 Use of Wood in Slovenian Contemporary Architecture

Slovenia has a long tradition of sustainable forestry, industrial refining of the raw material provided by forestry, and historical continuum in the use of timber in construction. In spite of wood tradition (Fig. 3.2), architectural material development, and the technological potential and function-based building regulations introduced in Europe nearly three decades ago, Slovenia has chosen its own path to reach a modern and industrialised use of timber in construction that allows a diversity of architectural expression and design possibilities (Kitek Kuzman & Kutnar, 2014).

A

B

FIG. 3.2 A+B: The House on Sv. Gregorij, Architecture: Jasna Starc, Arhitektura Starc *(Images by Blaž Zupančič, n.d.)*

The primary wood products used in timber construction in Slovenia range from sawn timber to various engineered wood products (EWPs). In mass-timber structures, glued laminated timber (glulam), cross-laminated timber (CLT), laminated-veneer lumber (LVL), and laminated strand lumber (LSL) are used for walls, floors, and roofs. In timber-frame structures, timber wall sections are assembled from studs and crossbars of various dimensions. For the exterior and interior surfaces, besides solid wood, various panel-based products are used, including drywall panels and gypsum board, particleboard, cement-bonded panels, fibreboard, oriented-strand boards (OSB), and LVL (Obućina, Kitek Kuzman, & Sandberg, 2017).

Although the production of CLT and its use in timber construction are increasing, the use of sawn timber has lost its historical dominance and has been replaced by a number of EWPs, which have made a significant contribution to the development of a new approach to contemporary architecture.

In Slovenia, several "techniques are available for the construction of buildings with supporting frameworks of timber. One way is to use structural wood members to form a frame which is covered by structural wood panels, where the foundations are generally of concrete. This building technology is often used in the construction of single-family houses but also in the construction of multi-storey buildings. Another technique uses CLT for the supporting framework, walls and joists, and the walls have to be insulated to give the building a high level of energy efficiency. The technique is well adapted to the construction of multi-storey buildings. A third technique is a system of columns and beams, where glulam is used to a large extent for the load-bearing structure." (Kitek Kuzman & Sandberg, 2016, p. 244)

FIG. 3.3 From the left: Prefabricated CLT elements are transported to the construction site and then assembled and erected manually – Waldorf School in Ljubljana, Slovenia.

The CLT products are expected to play an important role in the future for single- and multi-storey timber buildings in Slovenia – Vita Nova glass wooden house by Kager company. Timber offers great potential for the reconstruction and modernisation of existing buildings, mainly through additional storeys or roof extensions – Hotel Breza in Slovenia *(CBD d.o.o., Bruno Dujič, images by authors, n.d.).*

A contemporary Slovenian trend is "towards a higher degree of prefabrication, i.e. a greater part of the building work takes place at an industrial plant in a well-controlled environment with approved quality assurance. The actual on-site assembly of the building until the roof is laid takes only one or two days. The prefabrication can include various components such as wall and floor elements, roofs, trusses etc., but also modules, so called volumes. Both components and modules are prefabricated with insulation, installations, windows and doors. Prefabricated components of wood are relatively light in weight and can be erected to heights of several storeys using simple lifting equipment. With prefabricated wood modules, the total cost is up to 20-25% lower than to building on-site. This is partly due to a time saving of up to 80%. In Slovenia, most of the large house manufacturers offer off-site prefabrication houses." (Kitek Kuzman & Sandberg, 2016, p. 246)

3.3 Wooden Passive House in Croatia

The family house "ČV1" in the small settlement of Kupinečki Kraljevec near Zagreb (Fig. 3.4) is the first timber-constructed passive house in Croatia, built in 2003 with the use of brick and wood materials salvaged from a nearby traditional house. Experience in architectural heritage therefore represented one of the basic components of the new "culture-logical recycling" concept.

"ČV1" house is a great example of how to use a plot to favour the wider environment and energy efficiency, how to combine recycled materials from traditional architecture, and to fulfil requirements of the passive house standard at the same time. The south façade is open to the sun, while the north façade stays mostly closed. The house is two-storey, with open gallery space in the living room. The roof is single-pitched (to the north), and its overhang, together with the terrace in the second level, creates protection from summer sunshine while allowing winter sun to penetrate deeply into the house. One part of the roof is covered with vegetation.

FIG. 3.4 Family house "ČV1"in Kupinečki Kraljevec, Croatia *(Image by Ljubomir Miščević)*

The timber construction is made as a box-section (2x4") with 30cm of thermal insulation. The façade and ground floor space of the staircase on the north façade side are bordered by 120-year-old brick. The facade of the first floor is covered with 150-year-old oak planks.

Another attribute of the house is its advanced energy efficient windows and façade doors with a very high level of thermal isolation and other physical characteristics suitable for large south facing surfaces, especially in climates with large amounts of solar radiation.

The envisaged values of thermal physics parameters meet the requirements for passive house. Installed active systems include a heat pump (air heat exchanger) and ventilation system. The roof accommodates solar thermal converters and photovoltaic converters (Miščević, 2012).

Experience from utilisation has so-far confirmed presumed efficiency, although the house does not yet have an operational ventilation system. Large glass surfaces facing south provide almost all thermal energy needs during the winter.

4 Clay

Bricks (mud bricks, sun-dried bricks, or adobe) are among the oldest man-made building materials. Approximately 6000 years ago, floods from the rivers Nile, Tigris, and Euphrates provided deposits of mud and silt which formed hard sun-dried cakes that were easy to remodel and incorporate into walls. In the absence of other locally available materials, ancient builders discovered that clay bricks can be very durable, especially when properly shaped, and started to use mostly wooden moulds to provide standard dimensions for easier and faster assembling. In the city of Ur in Mesopotamia, bonding material for sun-dried bricks was bitumen slime. Later, the potters discovered that partially dried bricks can be burned to provide better results. The first closed kilns were introduced around 2500 BC. The development of glazing techniques around 600 BC allowed the production of mosaic tiles.

Past civilisations used sun-dried (Fig.4.1) or fired bricks as the main building material for capital structures. The Great Wall of China, the Pantheon and the Colosseum in Rome, and the great proportion of historical buildings in Western Europe and South America (post-colonisation), were built from clay bricks.

FIG. 4.1 Sun-dried bricks *(production and images by Kristijan Zver, 2007)*

Depending on the type of clay, nowadays bricks are produced by firing at temperature ranging from 600°C – 1100°C. Energy-consuming production process, carbon footprint and the amount of radiation made contemporary brick producers rethink about sun-dried bricks.

Raw material used for brick-making can be grouped into three classes:

- clay found near the surface, mostly in riverbeds;
- shale – clay-rich sedimentary rock subjected to high geological pressure, with variable hardness;
- fire clay found at the greater depth.

Early Balkan cultures used clay for building and pottery-making, as evidenced in Vučedol, Vinča, Butmir, Hvar-Lisičići and other Neolithic archaeological sites positioned near rivers Sava and Danube. In Vučedol culture, made famous by bi-conical pottery with typical ornamentation (e.g. the Vučedol Dove), a typical house was square or cylindrical, made of wicker and coated with clay. The floor in a Vučedol house was made of burned clay. Roman and Ottoman builders continued to use brick made in a traditional way, while during the Austro-Hungarian period new technologies were introduced. Vernacular brick architecture in the Balkans is characterised by the use of sun-dried "ćerpič" bricks made of clay with the addition of straw. The clay was also used for adobe buildings and as a plastering material.

A

B

FIG. 4.2 A+B: Clay mortar plastering
(images by Kristijan Zver, 2007)

Recently, the Academy of Clay was established in village of Karanac in Slavonia (Croatia). Here, the entrants learn how to make and use sun-dried clay bricks in new construction and in reconstruction. By offering programs for children, social events and other activities that attract visitors and tourists, the Academy aims to preserve tradition for future generations, i.e. to revive the traditional use of clay. Similar contemporary initiatives are found in other parts of the Balkans region as well.

TOC

5 Other Natural, Regionally Available, and Traditional Materials

When it comes to utilisation of bio-based, natural, and regionally (locally) available building materials and techniques, the tradition of ex-Yugoslav and Balkan countries is rich, and still visible through crafts and heritage sites. In modern times, nonetheless, the utilisation of some traditional bio-based materials, e.g. hemp, red, straw and sheep wool, has been almost abandoned. Besides traditional healing benefits, hemp was used in the past for production of durable fabrics and ropes. Reed was the most common plaster base before contemporary suspended ceiling systems and methods for wall coating were introduced.

Today, many producers of sun-dried bricks are (re)considering hemp and straw as supplementary materials. Similarly, reed is regaining attention as an easy obtainable material. Traditional bio-based, natural, and easily available materials should be revived in both new construction and in reconstruction, as their benefits to human health, environment, and local (circular) economy are significant. In this section, the advantages of utilisation of sheep wool and straw are considered.

5.1 Straw

Straw is an agricultural waste material that can be installed straight from the crop field. It is a product of a one-year process of photosynthesis, comprising cellulose, lignin, and silicon. Even though the potential of this bio-based, natural, and easy-obtainable material is huge, straw is practically considered waste today, and only a small percentage of the total generated material is being used, mainly in agriculture and farming.

The oldest existing building made of straw is a church in Nebraska, USA, constructed in 1886 with only bales of straw as loadbearing and insulating material without additional construction (http://www.nebraskahistory.org). The applied low-cost building technique is now known as 'Nebraska' or 'load bearing technique', and the culmination of its application was in the period between 1915-1930. Although the technique initially emerged from the need to build temporary dwellings, it demonstrated that the straw-bale buildings are unexpectedly long lasting.

The first house made of straw bales in Europe is the French "Maison Feuillette" (http://cncp-feuillette.fr/) built in 1921. The engineer, Feuillette, proved with his project that it was possible to build good quality homes in the post-war period by using agricultural waste. This house, together with a complex of ancillary facilities, persists to this day as a stable and healthy structure. In the early 1970s, straw-bale construction was rediscovered in the United States, Canada, Australia, and some European countries. The increased number of publications dedicated to straw utilisation in construction built the foundations for the development of international 'straw-bale movement'.

A *B*

FIG. 5.1 A+B: Straw-bale house in Čikečka Vas, Slovenia *(images by Kristijan Zver, 2007)*

The house in Čikečka Vas in Slovenia (Fig. 5.1) was designed and constructed in 2007 by Kristijan Zver, one of the leading promoters of straw-bale design in the region. His cooperation with architect Alja Petrovič resulted in development of many new initiatives and accordingly in the increased number of straw-bale houses.

Generally, there are three main current techniques for building with straw. The most common way is to use wood or some other load bearing system with straw-bale infill. The other is the 'Nebraska' or 'load bearing' technique, where straw bales are the only loadbearing system. The third possibility is to use straw (in bales or free) as a part of prefabricated element (e.g. at https://www.modcell.com/).

Like timber, straw represents a material with immense potential to reduce annual emissions of carbon dioxide from material production, construction, maintenance, and building waste storage. By using straw bale and timber, in combination with other traditional or contemporary energy efficient technologies, buildings can become carbon neutral, thus achieving the essential feature of sustainability (Alcorn & Donn, 2010). Straw-bale construction results in higher net carbon storage (3.3 t of CO^2eq) than biochar production (0.9t of CO^2eq) (Mattila, Grönroos, Judl, & Korhonen, 2012).

The key to understanding straw as a building material is the new 'Factor 10' development concept that reduces the amounts of primary and operational energy by ten times. In other words, a house made of straw consumes ten times less energy than a conventional structure, according to the comparison of U-values (Glasnović, Horvat, & Omarić, 2008). Straw belongs to a group of materials that have excellent characteristics in the case of fire (Klarić, Džidić, & Roso Popovac, 2016). The lack of air in a properly packed straw-bale structure, especially when plastered with clay mortar, makes it almost non-flammable. Besides fire resistance, it is necessary to keep certain standards concerning humidity and density, and to ensure that there are no grains.

The main problem with persuading investors to use straw is a lack of knowledge and common ignorance about its durability. Even when used as an exposed roof cover, straw can last for decades, providing good thermal and water protection. When it comes to usual myths about insects, rodents, and fire, it should be noted that straw does not possess any nutritive value, and if it is dense enough and well plastered, insects and rodents make no threat to this material. That is why investors and the wider environment must be properly introduced to all benefits of this bio-based, natural, and local material. To that end, there are several free online courses that can provide a very deep understanding of all aspects of building with straw, as well as many books and manuals available online. With raised awareness about health, permaculture, and sustainable lifestyles, there is a hope that straw will become a more appreciated, and hence more commonly used, building material in contemporary, energy efficient, and cost-effective construction.

5.2 Sheep Wool

Sheep wool accounts for sustainable building material which comprises, on average, 60% of animal protein fibres, 15% moisture, 10% fat, 10% sheep sweat, and 5% impurities (Zach, Korjenić, Petránek, Hroudová & Bednar, 2012). Besides washing (preferably with ecological soaps) and production of either soft or hard blocks, or flakes for blowing-in, wool insulation does not need any additional energy for production. The durability of wool is practically better than in other insulation materials (for comparison, insulation made of expanded polystyrene foam lasts for approximately 20 years). Wool can also be mixed into clay sun-dried bricks or clay mortars as micro armature.

Zach et al. (2012) describe sheep wool as:

- clean and renewable natural material source;
- comfortable and easy to handle without potential risk to human health,
- easy to recycle and eco-friendly;
- self-extinguishing material, as the fibres do not support combustion, but char at high temperatures;
- consistent and durable material, as there is neither change in volume nor the loss of elasticity;
- highly hygroscopic – able to absorb moisture up to 35%, without U-value change;
- excellent thermal and sound insulation.

The potential for sheep wool insulation production in Western Balkan countries is high, and it can be considered as a material that could improve local economy (both farmers and industry). In Bosnia and Herzegovina, a small factory producing 4cm, 7cm, and 10 cm thick soft-wool insulation panels opened recently. The first measurements of temperature changes before and after applying 7cm thick sheep wool insulation panels on walls and roofs were done for the “Tree House” in Buna near Mostar (Fig. 5.2). Results showed that afternoon temperatures during the mid-summer period decreased for more than 10°C.

TOC

A

B

FIG. 5.2 A+B: Wool insulation (wool-line) for "Tree House" in Buna near Mostar

6 Conclusion

Natural materials are gradually coming out of the shadow, where they have been for last hundred years. The conciseness about sustainability, life cycle assessment, health issues, and environment has made the building industry of today rethink the way our homes are built.

Present trends in the building industry show that there is a growth in sustainability demands. The document *The World Green Building Trends 2016* (Jones, 2016), predicts a growth of 60% in green building by 2018. The most important fact for green building justification is the improvement of the quality of the environment and its transformation (Roso Popovac, Ćehajić, & Klarić, 2016). Historical buildings, materials, and crafts can provide valuable lessons that were forgotten during the last century.

Natural materials with low environmental impact, regionally available, durable, reusable, or easily decomposable are increasingly interesting to home-owners and to the market. Awareness about health issues caused by artificial or toxic materials in our homes and workplaces, and the problems associated with construction waste and energy consumption are turning natural, regionally (locally) available, and bio-based materials into desirable goods, and an increasing number of architects and engineers are promoting their benefits. Permaculture is becoming a way of life and a relevant philosophy.

Materials like stone, wood, clay, straw, or sheep wool are not just healthy, affordable, and energy efficient choices for stakeholders and the environment, but also hold potential to boost local economies. Circular economy, instead of linear, can turn small workshops and local industry into businesses that are more profitable and acceptable to local communities. With the utilisation of traditional materials, related emissions of carbon dioxide and other harmful gasses can be notably reduced.

The materials presented in this work are rarely used as sole materials for contemporary structures. But when their utilisation is intensified by smart combining with other, contemporary materials, the negative environmental impact of the overall buildings will be significantly reduced.

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