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THE ROLE OF THE CONSTRUCTION MATERIALS INDUSTRY IN THE CIRCULAR ECONOMY

IMPOSSIBLE MISSION OR A REALISTIC FUTURE?

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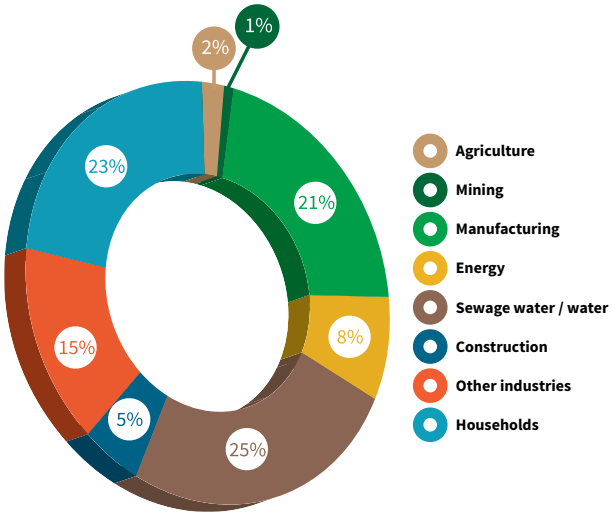
SUMMARY

One of the greatest challenges of 21st century consumer societies, while continuously extracting resources, is to find a solution to the problem of waste materials. Therefore, it is the shared goal of our society to establish a waste-free world. According to estimates, only one percent of the materials utilised actually remain "in use" 6 months after sales and it is practically impossible to track what happens to the remaining 99 percent. An ever-increasing proportion of corporations consider it one of their strategic goals to continuously utilise the materials they use. This concept is actually known as the circular economy which, due to consumers looking for sustainable solutions, the critical levels of raw materials and the breakthroughs offered by the new technological solutions of the fourth industrial revolution, has become a key element of corporate strategies.

Ratio of Waste Management, EU-28, 2016



Source: Eurostat

This system goes far beyond sustainable development as the circular economy is a model in which there are no waste materials and in which the products of today are the raw materials of tomorrow. The current system of consumer societies is typically linear, in which we manufacture, use and then discard products. Selective waste collection and the replacement of the fossil fuels of energy-intensive industries with alternative – typically waste-based – fuels, the usage of "waste" materials created from the processes of other industries as raw and supplementary materials are all key milestones in our attitude to waste, yet in themselves, they do not represent a solution. We need an approach and long-term thinking that allows us to know, as early as in the design phase, what will happen to the byproducts and waste created during manufacturing and the product itself after it's discarded by the user. In the circular economy, instead of ending up at waste disposal sites (and unfortunately, in the seas, forest and fields...), the products are reintroduced to manufacturing in the form of raw, supplementary or fuel materials, typically in a different industry.

The circular economy is about more than just recycling and is typically an economic model that spans value chains and industrial sectors, redefining the process of product design, manufacturing and usage and thus opening up new, previously untapped (secondary) markets for companies.

The goal of the European Union is transitioning to a circular economy, in which products, raw materials and resources retain their value for the longest possible time in the economy and the generation of waste is reduced to its minimum. Ensuring an European competitive advantage is based on establishing a sustainable, low carbon, resource efficient and competitive economy.

> ***Alongside the ever-increasing extraction of Earth's limited resources, the amount of waste produced is growing at a rate that is no longer manageable. The solution is the circular economy model, in which there is no waste and in which the products of today are the raw materials of tomorrow.***

In Hungary, the coordination and regulation of the transition to the circular economy – in accordance with EU regulations and principles – will be handled by the Ministry for Innovation and Technology (ITM). The Ministry plays a key role in establishing a regulatory environment that supports the "transitioning" of the Hungarian economy to the circular economy model. The industries are also committed to the transition to the circular economy and strive to maintain a continuous dialogue in order to establish controls that ensure the switch-over and the improvement of the competitiveness of the Hungarian economy and companies.

The circular economy is a model that spans industries (and national borders), in which regulatory, national and economic operators are involved in forming a comprehensive strategy and realising the transition.

The study shows that the concept of the circular economy, waste reduction and more effective resource management will increasingly emerge within the construction industry. This is particularly true in the case of the construction materials industry and the field of cement, concrete and the buildings, structures and works created from them. Sustainability, increased efficiency, incentivizing the reduced use of resources, research and development and innovation already play a key role in the strategy of industrial operators, thus establishing the foundation for transitioning to a circular economy. In Chapter 7, we will focus in detail on the current situation of the industry and the efforts it is currently making in this regards.

In establishing the circular economy model of concrete, the cement and concrete industry is faced with the task of ensuring that production is free of waste materials that require further treatment and becoming carbon-neutral by using a minimum of natural resources with as long a life-cycle as possible as well as making it 100 recyclable by the end of the process. The manufacturing of concrete already allows for assuming numerous alternative raw, fuel and supplementary materials from the byproducts of other industries as well as industrial and communal waste products. However, this is unimaginable without a well-functioning economic and regulatory environment focusing on:

- ***the adaption of the cement industry to the waste management hierarchy,***
- ***the realisation of CO_2 capture,storage, transport and recycling,***
- ***establishing the system for tracking construction materials,***
- ***standardisation and regulations that support innovative technologies and materials.***

1. FROM THE LINEAR TO THE CIRCULAR ECONOMY

Products have a lifecycle, which has become linear since the first industrial revolution, which means that it produced industrial raw materials and utilised them to create products, which were then subsequently used and finally discarded. The limited nature of resources (and the related cost increase), the development of technology, and the responsible approach of new generations led to the appearance of the principle of sustainability by the end of the 20th century: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Report, UN, 1987). In the spirit of sustainability, three areas must be in symbiosis, the economy, society and the natural environment. The main goal is the development of these three fields in a way that reinforces and is not opposed to one another. Corporate Social Responsibility (CSR) has also become the corporate manifestation of sustainability, which ensures the validation of economic interests while decreasing the environmental and social impact.

The circular approach extends this to the recycling, remanufacturing or reusing of products. The increasingly rapid technological advancement of the 21st century helps make economic processes more effective and offers solutions through which waste is reintroduced to the value creation processes.

There is nothing new about this approach as many scientists have been dealing with this for decades and it has become part of public awareness, while increasingly emerging in the strategies of corporations. There are three main factors behind the spread of the circular economic approach:

1. **Changing consumer needs:** Research shows that 30-40 percent of consumers are willing to spend more on products made of environmentally friendly or sustainable raw materials. This is particularly important for generations Y and Z (35-20-15 years of age), thus forcing corporations to operate in a responsible way, not merely supporting such principles in their communication.

2. **Scarce resources:** The increase in population requires more resources, whilst the Earth's resources are limited. We are now at the point where the WWF's (World Wide Fund for Nature) so-called "Earth Overshoot Day" (the date within a particular year on which humanity's resource consumption exceeds the Earth's ability to regenerate said resources) is coming at an ever earlier date (in 2019, this was 29 July), which means that in the period exceeding this date we are depleting the natural resources of the generations to come. The scarcity of resources also leads to significant fluctuations in the price of raw materials, which is disadvantageous to corporations and ultimately to consumers as well.

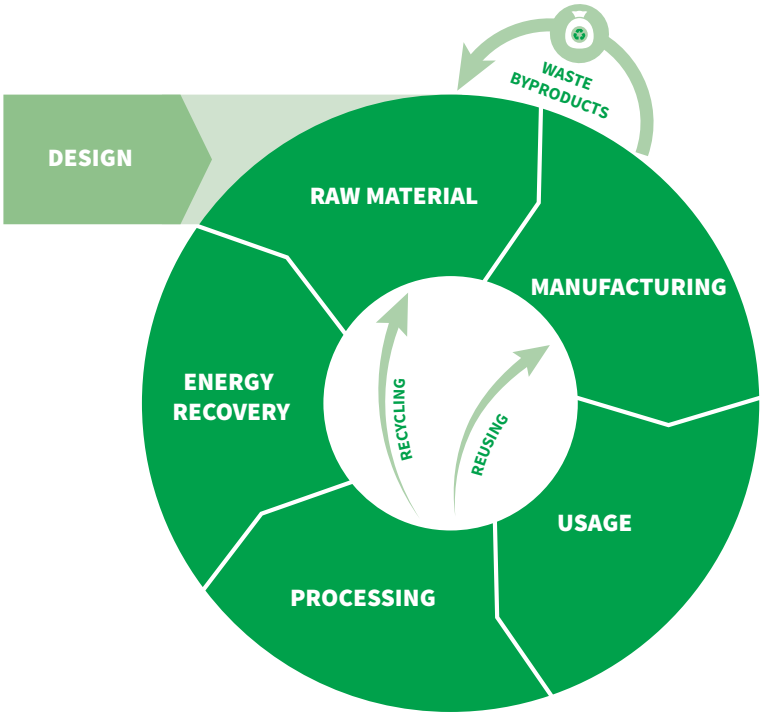
3. **Technological breakthroughs:** We are living in the time of the fourth industrial revolution, which is characterised by digitalization and a huge amount of data and its processing (the first was the textile industry and the steam engine – 18th century; the second was the heavy and chemical industries, electricity – second half of the 19th century; the third was programming and automation – 20th century 70s). As opposed to the first industrial revolution (when we became acquainted with waste materials), the fourth industrial revolution offers the opportunity to eliminate, or at least greatly reduce waste. Industry 4.0 is a technological model, which utilises renewable resources, keeping the limited materials of the Earth's resources in an endless cycle.

The sustainable approach based on the symbiosis of the economy, society and the natural environment extends the circular model to the recycling, remanufacturing or reusing of materials even across industries and national borders.

2. THE MEANS OF THE CIRCULAR ECONOMY

There is nothing new about the means of the circular economy (e.g. selective waste collective is one of its key milestones), yet these must be present throughout the entire value chain (from the design process and manufacturing to product usage and its reintroduction to the value creation process) and are to be used by operators in a coordinated way.

Circular economy model



2.1. Sustainability

As early as in the design phase, raw materials and functions must be identified which can minimise the ecological footprint of the product throughout its complete life cycle. They design products that are durable (remaining in slow circulation and used for a long period of time), have a modular structure (with elements that are readily available and replaceable) and use raw materials that are sustainable, reusable and degradable.

2.2. Sharing

The success of companies based on a sharing economy (e.g. Airbnb) is mainly based on information technology developments and the change in human needs (e.g. ownership). Experts expect the greatest breakthrough from self-driving vehicles that don't require us to maintain a car (and parking space, garage etc.), but rather we can order one to our house when needed and dispatch it once we're done using it. Sharing requires fewer products, thus reducing the amount of waste.

2.3. Maintenance, Repairs

Industry 4.0 provides devices (e.g. sensors, IT solutions) that can be used to maintain the product's value in use for a longer period of time. Maintenance is a consciously structured activity that prevents malfunctions, while repairs help restore the product's value in use. These post-sale services can amount to even three times the turnover of the one-time sale, not to mention brand loyalty-based advantages.

2.4. Renewal

Similarly to repairs, the goal here is to restore the value in use, yet in this case, the intervention is of a much bigger scale, in order to restore the product's original value in use. Apart from retaining the original functions, an aesthetic upgrade results in a novel condition, yet an energy-efficiency renewal greatly boosts the use in value while decreasing the environmental burden.

2.5. Remanufacturing

With a minimum resource input, the goal here is to restore the original level of use or create a new product. During this process, the product is deconstructed, repaired or replacement and finally reassembled, thus decreasing the amount of waste produced, along with the raw material and energy demand.

2.6. Recycling

Recycling is about more than just selective waste collection and has two different types: in the case of value-increasing recycling, we create an entirely different product without deconstructing the material, whilst in the case of value-reduced recycling, the material is decomposed and further used in a different quality. Recycling during the manufacturing process: using or recycling the byproducts generated during the manufacturing process.

2.7. Reusing

If a product no longer has value for its owner, they can sell or gift it. Thanks to the opportunities offered by Industry 4.0, apart from traditional channels (e.g. collection points of charity organisations), a number of platforms have been established that have greatly simplified the process of reusing, making it more convenient.

3. INDUSTRY 4.0 IN THE CIRCULAR ECONOMY

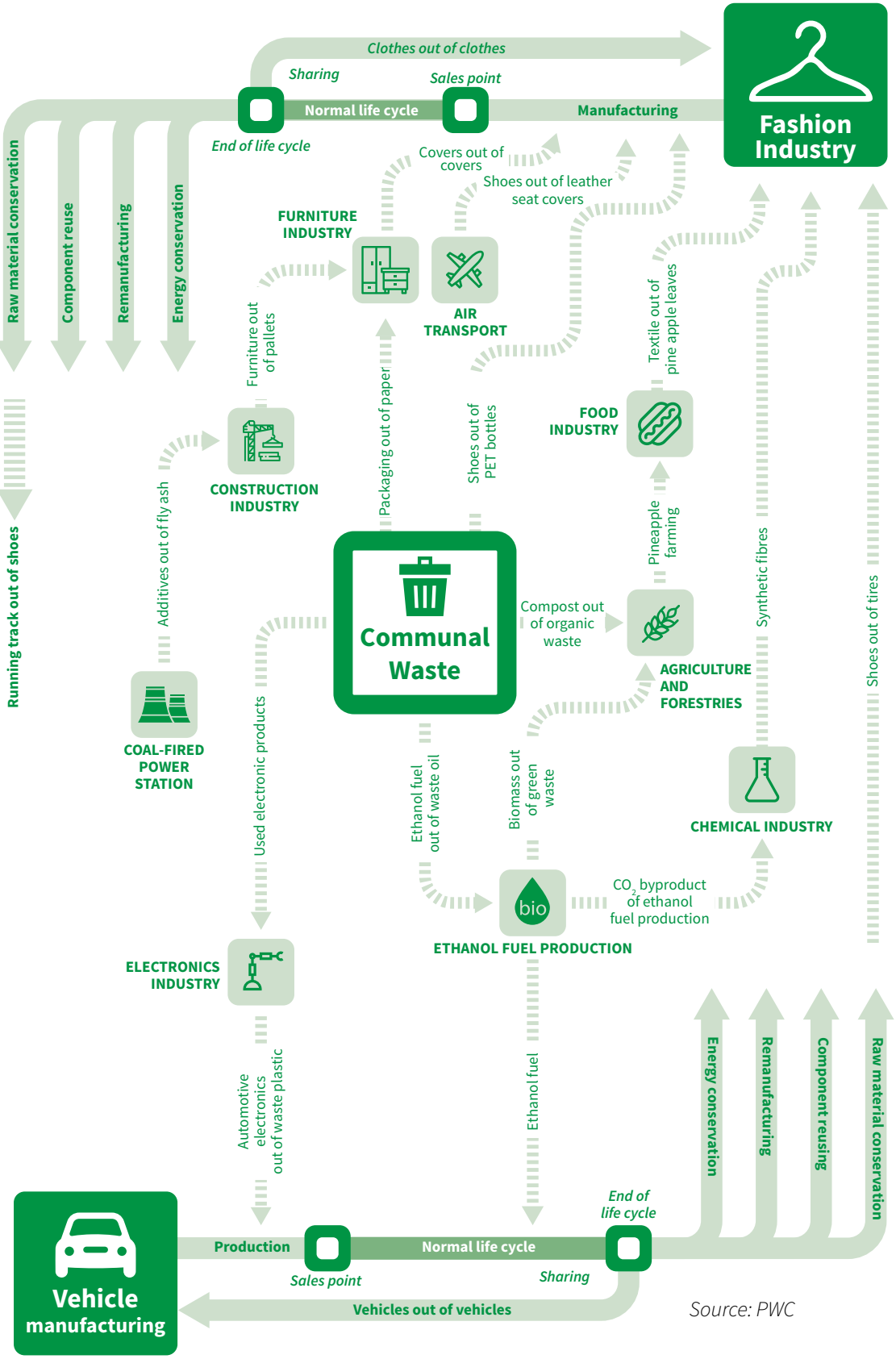
Moore's law, based on the observations of technological advancement (according to which the complexity of integrated circuits doubles about every 18 months) has been verified, therefore we are now witness to technological development of such scale that has brought about the 4th industrial revolution. Devices of this nature can accelerate the transitioning to a circular economy, while the devices themselves continue to develop, thus helping the economy become waste-free. Such innovative technological solutions include:

- Online sharing and data analysis offer new opportunities in the fields of IoT technologies and maintenance, as well as in the implementation of smart waste collection.
- Robotics based on artificial intelligence and machine-learning algorithms allows for machine-based work in the case of a growing number of activities, thus reducing waste and expanding the life cycle of a product.
- 3D printing offers a range of opportunities, including the manufacturing of complex, unique shapes and parts even for limited-run series (thus reducing the need for stocking). The unique production of non-manufactured parts plays an important role in extending the life cycle of a product or reusing old products.
- With the advancement of raw materials, the same raw material can be produced with fewer resources and can be biologically degraded or disassembled and recycled.

Industry 4.0 is a technological model, which utilises renewable resources, keeping the limited materials of the Earth's resources in an endless cycle, thus accelerating the transition to a circular economy, while the materials themselves also continue to develop, thus helping the economy become waste-free.

4. INDUSTRIAL INTERCONNECTIVITY

The circular economy is a system that spans national borders and industries, during which the waste or byproduct of one company will be the raw material of a company in another industry. This takes place if the company is unable to reintroduce it to its own value chain, yet a different company or industry is capable of adopting it in its own value chain in an unchanged form, or with a minimum of changes. This is already a common practice for companies, as illustrated in the following diagram:



Source: PWC

Currently, we are in the initial stage of the transition to the circular economy, while numerous governments (EU) across the globe are making efforts to facilitate the transition to the circular economy, establishing regulations and supporting such ambitions of companies.

Key areas of the circular economy model:

- Let's examine the product and see whether raw materials can be sourced from it without a loss of function or value (e.g. circulating it in powdered or concentrated form).
- Let's see if our product can be created with sustainable raw materials. If not, let's use innovation and research to head in this direction.
- Let's introduce a business model that increases consumers' consciousness of product (re)usag).
- By establishing the economically viable maintenance and repair infrastructure of products, we will encourage keeping the product in use for as long as possible.
- With two-way logistics, let's make it possible for consumers to return the product after use.
- Let's search for and establish a secondary market for used products or byproducts beyond the initial consumer.
- Let's closely monitor initiatives, set of proposals and business solutions that support the circular economy.

Every industry (oil, textile, food etc.) plays its own role in the circular economy model, yet hereinafter we will be dealing with the construction industry.

In the circular economy, the waste or byproduct of one operator is the raw material or fuel of an operator in another industry.

5. CONSTRUCTION INDUSTRY

Due to its impact on society and nature (requiring a great amount of raw materials), the built environment must be addressed when talking about sustainability and the circular economy. For this reason, it is particularly important to capitalize on the circular interfaces of the construction industry. Its impact on the environment doesn't stop when the construction is completed, as the usage life cycle of our buildings also burdens the environment: over 40 percent of primary energy consumption is tied to buildings, which are also responsible for a high level of harmful emissions. Upon the completion of its life cycle, the demolition of buildings also has a major impact on the environment.

As a result of this, the circular economy isn't merely evidenced in the manufacturing and usage of construction materials, but also in the fields of operation and maintenance and finally, in the rehabilitation and demolition of aged buildings as well as in the treatment of waste materials produced in this way. As early as in the design phase, a number of professionals from different fields (architects, mechanical, electrical, static engineers etc.) are cooperating, therefore the harmonisation of their activities is of great importance for the sake of compliance with the increasingly strict regulations on buildings. The global project of the World Green Building Council, NetZero, aims for the carbon emissions of all buildings to be nearly zero by the year 2050. Beyond this project, there are a number of rating systems (BREEAM, DGNB, LEED) that facilitate the integration of buildings into the circular economy. The increasing number of buildings with IoT (Internet of Things) technology – entailing higher construction costs – also increases the value and practicability of real estate when combined with lower operational costs. Nowadays, we are no longer focusing merely on smart offices (which greatly contribute to reducing the ecological footprints of offices), but are also using smart beacon technology that pinpoints the real-time location of employees to generate data on unused spaces, functions and the occupancy of objects and even queuing. This allows for the further optimization of space utilization, combined with, for example, increasingly wide-spread home office work. Company cultures are changing and by applying technology, the arrangement of the office environment and work schedule can significantly improve work morale and have a stimulating effect on those performing intellectual work.

We design our buildings for the long-term and their lifespan is accompanied by repairs and maintenance. In the case of buildings that have lost their function, it is increasingly common to resort to reconstruction with a low level of environmental burden, which poses a serious challenge due to old technologies and standards and despite good intentions, it often transpires that it is not technically/economically viable. With the advancement of technology, there are a growing number of examples where this is realized, often as part of complete city (district) rehabilitation programmes.

The greatest "waste generating factor" of the construction industry is tied to demolition, primarily in the form of airborne dust and the large amount of environmentally harmful demolition waste, which can be significantly reduced. With the development of processing and demolition technologies (which are practically carried out in reverse order compared to construction), the demolition waste can be selected (or further treated when necessary) and practically all construction materials can be used for their material or energy in the circular economy model (e.g. steel and glass waste can be immediately used as the raw material of new products, or even recycled).

One of the model projects in Hungary was the demolition of a high-rise building in Pécs, which resulted in 22 thousand tons of concrete waste. This could be easily used as filling material for road constructions or even to make concrete. The technologies were at our disposal and the project showed how a well-planned demolition process could serve the purpose of the reuse of demolition waste materials. The call for tender for the demolition of the building outlined provisions for the collection, transport and treatment of the concrete as well as for certifying the concrete – which made up most of the waste – as a product. This has enabled a growing number of standards of construction products to now provide for the reuse of demolition waste and its technical specifications, allowing, for example in the case of concrete, for it to be reused as the raw material of new concrete or as an auxiliary construction material (according to its respective rules).

Herein follows an example of the set of criteria of a "green" public procurement tender procedure (EU recommendation):

- Performing a life cycle evaluation and the impact of the main elements on the life cycle.
- Carbon footprint measurement, assessing the global warming potential of main road components.
- Certification of the compliance of main components with reused material and recycled material content specifications.
- The requirement for reducing the CO_2 emissions resulting from the transport of high-mass materials.

Major resource-efficiency performance can be forecasted within the industry and the construction industry value chain and processes must be reconsidered. The advancement of the manufacturing of construction products, sustainable installation

procedures and modern technologies and raw materials that place significantly less burden on the environment open up new opportunities for the industry. The earliest possible transition is of vital importance for the Hungarian economy as the intensification of international competition, lasting economic growth and the creation of new workplaces are key governmental efforts. Therefore, the governmental strategy under preparation targets the general development of the construction economy, advancement in the domestic manufacturing of construction materials and life cycle evaluation-based objectives related to reusing and recycling.

Politics play a key role in establishing a low carbon, circular and competitive construction sector, which can be achieved with concerted efforts. There is no “silver bullet” or single solution available to us, the expertise and considerations of planning architects, specialist designers, legislators, those responsible for establishing standards, material manufacturers and construction industry contractors are indispensible for successfully completing the transition. However, through the cooperation of all the operators in the value chain, a truly carbon neutral future can be achieved. This initiative is referred to as 5C, which means: Clinker, Cement, Concrete, Construction, and Carbonation.

We require a regulatory and normative framework, which:

- ensures identical conditions of competition between regions and industries,
- is material neutral and based on life cycle performance,
- equally considers both supply and demand,
- supports breakthrough technologies and their development.

Capitalizing on the circular interfaces of the construction industry is a key issue, as upon concluding the construction of our buildings, they still place a burden on the environment and upon the completion of their life cycle, the demolition of buildings also has a major impact on the environment.

6. CONSTRUCTION MATERIALS INDUSTRY

Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011 (as well as Government Decree 275/2013 (VII. 16) on non-harmonizing areas) featured demands on buildings in which a new element was the sustainable use of natural resources. The interests of both the regulatory side as well as the economic interests of manufacturers point in the direction of handling the means of the circular economy as part of corporate social responsibility, applying these criteria to their investments and developments. Manufacturers are committed to applying best available technologies (BAT). Industry 4.0 also appears in current manufacturing technologies, as an increasing number of product standards take scarce resources and recycling into consideration.
The European industrial sector (including the construction industry) must be carbon neutral and circular in nature, while retaining its competitiveness – this is no easy task in the current global environment.

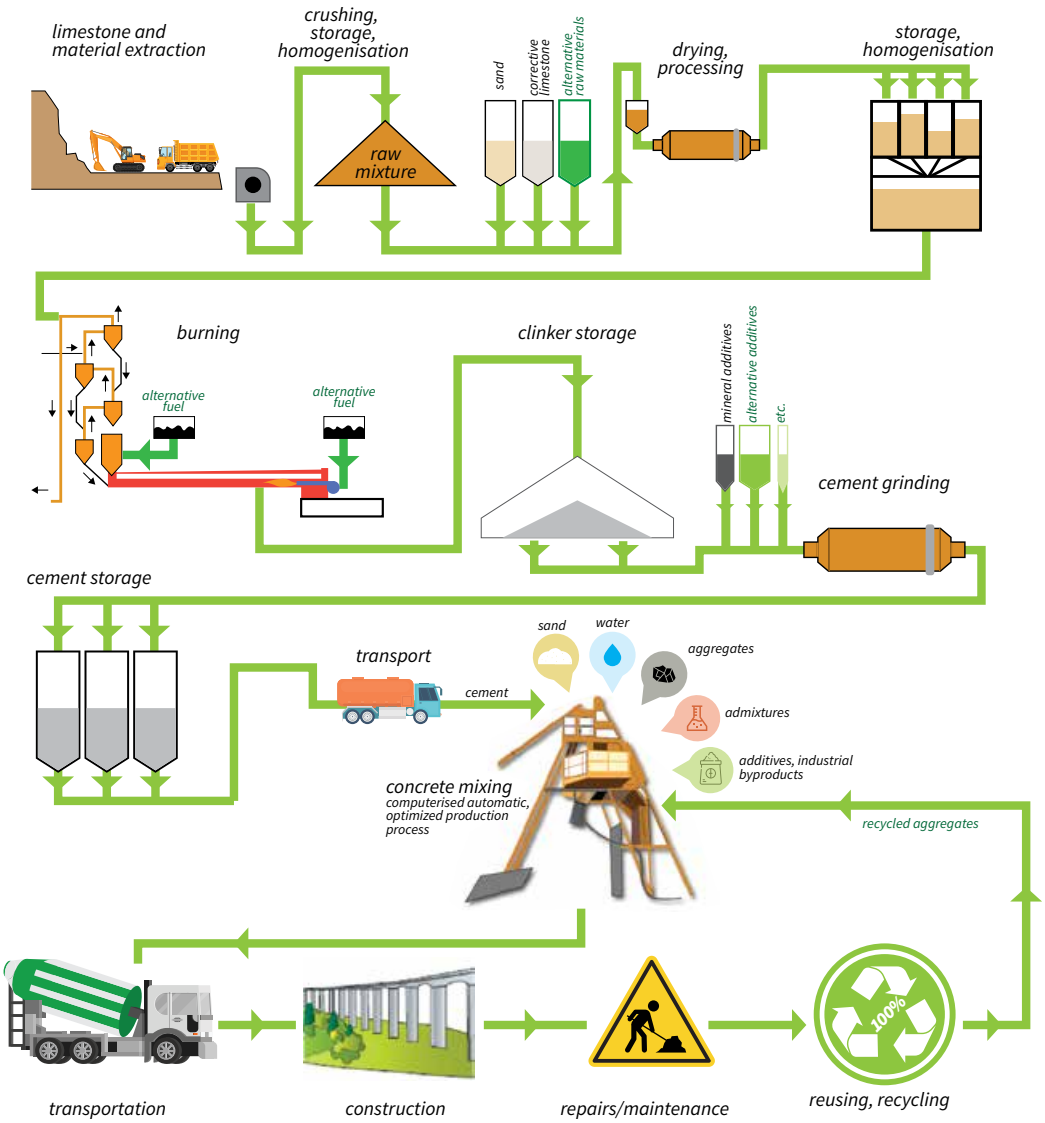
After water, concrete is the second most frequently used material on Earth, which is used in the greatest amount in the construction industry. It has century-old traditions, yet is still innovative, long-lasting, safe and has a wide range of applications, when applying 21st century technology. It is the true and indispensible engine of development, the foundation of sustainable and modern construction and the circular economy would be unimaginable without it. Due to its importance, the most waste is produced from this material at the end of its life cycle, therefore in the following, by reviewing the entire life cycle of concrete, we will present the role of the industry in the circular economy and the previously realised, still ongoing and future developmental opportunities, thus the industry's transition to a "circular nature".

The technologies of construction material manufacturers based on century-old traditions already bear witness to Industry 4.0; the sector must become carbon neutral and circular while retaining its competitiveness.

7. CONCRETE IN THE CIRCULAR ECONOMY

Concrete is a mass produced, long-lived (the dome of the two thousand year-old Pantheon is still the largest unreinforced concrete dome in the world), environmentally friendly material that can be installed without damage to the environment in the linear economic model and can even be used for the recultivation of mines. Its production entails environmental impact, yet thanks to its long lifespan, it is still a "competitive" construction material and a little known fact is that throughout its life cycle, it absorbs a significant amount of CO_2 from the air – whilst its manufacturing, mainly due to the cement technology, produces CO_2. In order to understand the transition to a circular economy and the opportunities inherent in concrete, it is indispensible to analyse its life cycle and familiarize the cement and concrete manufacturing technologies.

The lifecycle of concrete



Due to its volume, even small measures introduced in the production of concrete (mainly cement) are major steps towards a carbon neutral, circular economy.

In the following, we will present – through the value chain – the roles of the individual technological elements over their entire life cycle in the circular economic model. In the case of the individual elements, we will present the current state of the industry and the developments that are expected, or required in order to transition to a circular economy.

7.1. Extraction, Mining

The clay and limestone are fragmented with blasting and are extracted with front loaders and excavators. Thanks to the continuous development of mining and transport technologies, the industry's environmental burden are continuously decreasing and they are using technologies that allow returning extracted areas to nature in nearly their original state. At the same time – thanks to the spread of alternative raw materials – the natural raw material demand is decreasing.

7.2. Limestone and Clay Shredding

The blasted stone and excavated clay are fragmented, shredded and homogenized, establishing the chemical composition of the raw material. Apart from continuously developing the efficiency of the technology, the development of the miscellaneous active elements is also of key importance for the industry in order to use more diversified and less carbon intensive (e.g. steel slag) raw material mixtures in its technology.

7.3 Raw Material Grinding

The prepared raw material mixtures are grinded in a roller mill until achieving the consistency of flour. With the advancement of grinding technologies not only has the industry achieved economies, but also more favourable milling properties as a development that lasts to this very day.

7.4. Clinker Burning

The hot waste gases discharged from the rotary kiln gradually heat the kiln dust in counter-flow within the heat exchange tower and the chemical processes are initiated: subsequent to the decomposition (decarbonation) of limestone at 800-900 °C, the kiln hot meal is fired at a high temperature (approx. 1450 °C), which "shrinks", forming a hot melt. At the end of the procedure, chemical reactions take place, during which the compounds (so-called clinker minerals) are formed, which determine the properties of cement. CO_2 is released during the chemical decomposition of the limestone (which is referred to as technological discharge) and maintaining the temperature that satisfies the heat demand of the chemical processes and chemical reactions results in further emissions (emissions from combustion).

The cement industry is an innovative sector characterised by continuous R&D and technological investments:

- **Heat consumption:** with the modernisation of factories and the construction of new, modern plants, the energy efficiency of kilns has been greatly improved. The energy intensity is influenced by factors such as the humidity rate and flammability of raw materials, the type of the kiln, the manufacturing environment and the cement standards.

- **Fossil fuels** are being **replaced** by alternative materials (pre-treated waste materials, biomass), with a solids content that is incorporated into the clinker, replacing primary, mined raw materials, utilising its energy as well as material content without influencing the quality of the "end product" without leading to any excess harmful emissions. As this process is only typical of the cement industry, in order to distinguish this procedure from waste incineration and the collective incineration of materials (co-incineration) it is technically referred to as co-processing, during which they process waste flows (such as used tires, certain types of plastic and other chemical materials) that cannot be utilised with conventional procedures to cover the energy demands for the formation of clinker minerals. The technology already exists and with the appropriate amount and quality of waste materials, up to 90 percent of fossil fuels can be replaced.

- As a result of efforts to **reduce the amount of clinker** in cement, the clinker/cement ratio, – due to the introduction of composite and heterogeneous cements – has dropped to 76.4 percent. Thanks to the developments, the new future cement standard will allow for the introduction of further cement types low in clinker, however, the sustainability of the available clinker replacement materials and hydraulic supplementary materials (e.g. fly ash from coal burning, granulated blast furnace slag) is questionable.

- In the future, the greatest breakthrough can be achieved through **carbon-dioxide capture**, during which the pure CO_2 from process emissions can be captured and used as a raw material for fuels, carbon fibres or even new construction materials.

- Tests are already underway on a **new type of clinker**, which is manufactured at a temperature that is approx. 250 °C lower than what is use for the current types. If successful, the CO_2 technological emissions will be reduced by a further 30 percent.

- Experiments/ studies are already being conducted on the **electrification of cement production**, using wind or solar energy combined with the capture and utilisation of CO_2.

7.5. Cement Grinding

The semi-manufactured product emerging from the kiln, the clinker, is rapidly cooled and placed in a storage site/silo. The set clinker is grinded with 4-5 percent controlling agent content (plaster, REA plaster) and miscellaneous additives (granulated blast furnace slag, fly ash, pozzolanic ash, pure limestone) to produce cement.

Grinding is an energy-intensive process and its technology has seen enormous change over the recent decades, yet this progress hasn't stopped and the future will see the development of further shredding, particle size and classification technologies. The cement industry continuously reduces the clinker content of cement with additives, thus cutting down on CO_2 emissions. The current cement standard differentiates 27 types of cement, 26 of which have a clinker content of 20-94 percent. Continuous developments allowed for the appearance of new low-clinker cement types – while retaining their installation features and quality – and thus reducing CO_2 emissions and the use of natural resources.

The cement of various qualities (52.5; 42.5; 32.5) and composition stored in silos can be shipped after a few days of setting.

7.6. Cement – Innovative Binder Development

In regions where there are a range of available raw materials (e.g. fired/calcined clay, iron, bauxite) instead of using Portland cement clinker, an innovative binder with lower carbon emissions can also be a sensible solution. As the strength, durability and safety of concrete is ensured by clinker-based cement, the cement industry is continuously conducting raw material research to find lower cement types with lower CO_2 emissions. Promising experiments are being conducted for the production of various types of cement, which enable the use of less limestone and clinker with lower flame temperature and grinding energy demand, which can result in cement production technology that yields further nearly 30 percent lower CO_2 emissions.

7.7. Ready-Mixed Concrete Production

Concrete technology has greatly developed over the recent decades. Nowadays, apart from designing for strength, various environmental effects play an increasingly greater role in the design process. The different types of concrete are produced to be resistant to such environmental effects, therefore their expected working life will be significant increased, thus reducing the environmental impact.

Current, modern types of concrete can be produced in computer-controlled ready-mix concrete plant, where apart from quality, strictly regulated technology can guarantee the optimal feeding of components and the production of the planned concrete mixture. Modern types of concrete consist of aggregates, binders, mixing water, admixtures and additives. Depending on the regulations for the planned concrete, the aggregates can be replaced with different proportions of demolished and prepared concrete (experiments are also being conducted for the reuse of other materials, e.g. glass, brick), thus reducing the amount of mined raw materials. The binder in concrete is clinker-cement, which has a significant impact on the concrete's carbon footprint. The carbon footprint can be further reduced with the more efficient use of various types of cement, replacing cement content with aditives (granulated blast furnace slag, fly ash and new sustainable supplementary materials), optimizing the mixtureand the fine-tuning of aggregates and water usage. Some carbonate binders for which the recycled aggregates are exposed to ultra-high CO_2 levels in a regulated maturing rooms, achieve a chemical transformation that captures CO_2 in the concrete. As opposed to conventional hydraulic binders (that react to water), carbonate binders do the same with waste gas-based CO_2, resulting in a much shorter (day-long) setting time. Some available technologies can save 250 kg of CO_2 per tonne during the cement production process with innovative clinker components, whilst the concrete itself lastingly captures a further 300 kg of CO_2 per tonne of cement. This amounts to reducing the concrete's CO_2 footprint by 50-60 percent.

Beyond the available concrete properties, today's highly developed admixtures also play a major role in durability and allow for creating engineering structures that are leaner compared to identical concrete properties, thus resulting in lower natural resource use and environmental impact.

Modern ready-mixed concrete production technology plays a key role in recycling and offers further opportunities for reducing concrete's CO_2 footprint.

7.8. Incorporation, Concrete Element Production, Construction

Thanks to the development of construction technologies and changes in approach, increasingly less waste is produced at construction sites and a smaller mass of material is installed. In the case of foundation work, precise securing of the excavation pit can minimise excess use, while observing the requirements of construction technologies can reduce construction and demolition waste.

In the case of special safety demands, prefabrication is an optimal choice as precast concrete factory allow using precise, controlled technology. However, this is implemented at construction sites exposed to weather conditions where various environmental effects and the activities of multiple disciplines "hinder" one another. Modern precast concrete factories apply technologies that are tailored to demands and prepared concrete elements are manufactured for further assembly tasks based on 3D designs. These include designing a structure by identifying the location of a luminary in advance instead of boring it out on the site, generating unnecessary waste. Moreover, the use of precast elements also entails a shorter construction time, thus reducing the environmental impact of the construction process. The appearance of 3D printing in construction work is a new future challenge. Its application is justified by a lack of labour, yet its true advantage lies in its flexibility and waste-free implementation. The technology is already available and there are 3D printing robots which only require human monitoring that can store 3D plans in their memory and can construct specific structures for which the materials are available, thanks to the innovation of concrete. These aren't merely boundary walls, but also structures that use flexible shapes and in which the spaces for electricity, building service machinery and additional elements are already identified, therefore there is no need to bore these out on site. This can save time as more precise structural solutions are created in a waste-free manner.

7.9. Maintenance, Repairs

Well-planned, implemented and after-treated concrete (ensuring the concrete's undisturbed chemical hydration) exposed to the planned environmental effects has a minimal maintenance requirement. The concrete structure will be durable if it can tolerate the mechanical, deformation strain and environmental impacts without damage during its planned work life. To this end, the standard has introduced so-called environmental categories and presents recommendations for the demands of the various categories. The maintenance of concrete primarily involves the regular inspection and maintenance of surface and connecting structures (e.g. the joining material of expansion joints) in order to ensure the longest possible work life. As a result of external and internal impacts, concrete structures can suffer damage that necessitates concrete repairs. We are now in possession of materials and technologies for the maintenance and repair of concrete – or for prevention purposes during the construction – which can ensure and extend the work life of the concrete.

7.10. Renovation

Concrete is an extremely durable construction material, nevertheless the various physical/chemical impacts during its work life can damage its surface or deteriorate its structure. We now have a wide range of materials and technologies to choose from for surface renovation purposes, including the buffing or impregnating of its surface or even the application of new patterns. The most problematic issue is the damaging of the reinforced concrete structure to such an extent that the steel bars become visible. Even in such cases – when not justified from static engineering perspective – there is no need to demolish these structures as the damage can be repaired through renovation. An anti-corrosive adhesive coating is applied on the steel bars and the concrete can be covered up with a special grout, yet for example, in the case of pillars, we can also employ a concrete jacket, which can restore or increase the load-bearing capacity of the structure.

Thanks to its long work life, in some situations the structure or building can receive a new function. There have been numerous examples of this, e.g. the reconfiguration of a concrete water tower into a residential flat or even the residential use of a concrete cement silo subsequent to its renovation.

7.11. Demolition, Recycling

As we saw in practice at the demolition of the high-rise building in Pécs, the recycling of – suitably prepared – concrete waste is becoming increasingly common. In the linear economic model, we thought that a significant portion of this can be deposited in landfills without any environmental impact, or used for infilling or as the foundation of roads. Concrete buildings that have lost their function and must be demolished will "produce" an ever greater volume of concrete waste, therefore there will be an ever-greater available amount of such materials, combined with the need to reduce the use of natural aggregates, therefore it's obvious that concrete should be recycled. We are only at the very beginning of this process and the use of

concrete as an aggregate typically only amounts to a few percent. Nowadays, there are no technical reasons that prevent concrete from being used as an aggregate and we are in possession of the necessary experience.

The MSZ 4798:2016 concrete standard regulates the issue of reclaimed wased aggregates from fresh concrete as well as hardened concrete unused in the construction process. The MSZ EN 12620:2002+A1:2008 Aggregates for Concrete standard lists a number of demolition materials apart from concrete as the components of course stone aggregates remaining from demolition, which provides opportunities for recycling materials such as glass or bitumen. The Technical Guidelines for Roadworks also support the recycling of materials. The assumption that concrete made of recycled aggregates has poorer qualities than concrete with regular aggregates is mistaken. Experiments show that appropriate care, regular raw material inspections and precise composition planning can result in concrete with identical or even more favourable properties than concrete made with regular aggregates For example, eco concrete is an available, functional technology, in which recycled, prepared and washed aggregates are used instead of mined gravel and sand.

7.12. The Role of Concrete in the Built Environment

In Europe, 36 percent of carbon-dioxide emissions originate from buildings, whilst a further 40 percent are from energy consumption, therefore the close scrutiny of the entire life cycle of infrastructure and buildings is indispensible for promoting the reduction of emissions. In reality, cement and concrete absorb CO_2 during their work life, therefore they play a key role in this process.

Cement and concrete play a key role in all the available devices for reducing CO_2 emissions (e.g. nearly zero-energy buildings, energy-efficient renovations, building management, low carbon-dioxide emission energy supply).

Building Heating/Cooling

The annual energy consumption of conventional buildings is 150-200 kWh/m^2 per year, which is 50 kWh/m^2 ower in the case of modern concrete buildings, thanks to thermal mass flow, permanent air tightness and other solutions. Thanks to transitioning to renewable energy sources and efficiency gains, concrete offers the best solution for utilising the advantages of low CO_2 emission energy. The reason for this is that concrete is suitable for storing energy in the thermal mass flow of buildings, while flexibly adapting to the changing demands of renewable energy sources.

The superb heat storage capacity of concrete can be utilised for the storage of thermal energy produced by solar power stations and also as a “buffer” for the heating and cooling systems of buildings. The beneficial heat storage capacity of concrete is primarily due to the large mass of concrete, which basically functions the same way as the thick walls of castles and churches built centuries ago. In the case of our buildings, the pipeline network of the heating-cooling system runs through the “core” of the concrete elements (floor, ceiling and walls), ensuring a pleasant, draft-free and even heat distribution climate. The entire system operates in a narrow temperature range around room temperature (interior ±5 °C), while the heat storage and release is provided by the huge heat transfer surface of the concrete elements. An optimised system can ensure low landed and operational costs.

Durability

Buildings and structures are designed for at least fifty years, yet in the case of major structures (e.g. bridges, tunnels, dams) this can be hundreds of years. Naturally, the structure won’t collapse at the end of its design work life, yet just as all artificial materials, it requires maintenance during its life cycle, which is minimal compared to other construction materials. For example, let’s take a concrete road, which only requires preservation maintenance over its first 20 years. As a result of its longer work life, concrete roads also support road traffic as their use requires fewer roadblocks and traffic diversions. In the case of the renovation of existing buildings, thanks to its durability, concrete can undergo multiple cycles of restoration before its reconstruction. The renewal of the concrete building stock including its energy efficiency renovation often offers economic, energy efficiency as well as social benefits.

Smart Concrete

Modern building management devices consider environmental parameters such as consumer behaviour, thus the heating and cooling system controls based on thermally activated concrete communicate with the electricity networks, utilising the opportunities offered by renewable energy.

The Role of Concrete in Renewable Energy Production and Low CO_2 Emission Transportation

The CO_2 emission reducing effect throughout the entire life cycle of concrete also has great significance in its infrastructural usage, thanks to its durability and resistance. Concrete bridges and tunnels reduce the emissions of vehicles, while a great number of CO_2 reducing investments (e.g. dams, wind power stations) are unimaginable without concrete.

Innovative Concrete Solutions

Technologies and innovations play a key role in making the construction industry carbon neutral, therefore the cement and concrete industry continues its traditionally innovative CO_2 reduction strategy throughout the life cycle of concrete. However, the efforts of the cement and concrete industry are not enough to achieve this goal, as they must be supplemented with innovative elements that encompass and even transcend the entire construction industry, such as:

- Greater precision thanks to digitalized industrial production and 3D printing and the optimisation of the entire life cycle reduces CO_2 emissions.
- The engineers must also progress in designing structures that increase the modular nature of construction. Throughout their long work life, buildings can undergo a change of function, therefore building elements must become modular and reusable with solutions that reduce the required amount of materials and waste, while increasing the efficiency of the material. Concrete is the best material for this purpose.
- Concrete can be effectively used to store the peak energy due to renewable energies, providing year-long heating for buildings without any additional costs.
- The reuse of precast concrete elements reduces the carbon-dioxide footprint of buildings by over 30 percent resulting in a significant reduction.

7.13. Carbonation

A lesser known fact about hardend cement is that it absorbs CO_2 throughout its life cycle as concrete or cement stone. This is a natural process that improves the strength of concrete by the contraction of the pore structure. During the life cycle of the man-made structure, this absorption capability can amount to 25 percent of the CO_2 emissions of cement produced with modern technologies. This isn't taken into consideration in the current system of glasshouse gas emissions, despite its significant amount.

The carbon-dioxide capture through the surfaces exposed to air is a natural process. Reinforced concrete structures are designed (for the sake of preventing the corrosion of steel bars) so that this process would slowly take place over the structure's work life and more rapidly after demolition. Optimizing the recycling of construction elements and demolition waste allows maximising the CO_2 capture of the carbonation process.

7.14. Summary Evaluation of Concrete

Concrete plays a key role in present and future construction, thanks to the experience and innovation behind the materials and its outstanding properties. We can also identify counterarguments against concrete that inevitably arise in the case of a material used in such large quantities. It plays a key role in construction and has undisputable importance in establishing a carbon neutral future. Whether it's the foundation of wind turbines, water or tidal power plant projects, energy efficient buildings, the transport infrastructure or adapting to climate change, the flexible adaptability and durability of concrete makes it indispensible in the value chain.

Concrete already offers incredible sustainability advantages and the industry is working hard to play a key role in the circular economy. The global increase of population and expanding cities result in using concrete – as a locally sourced construction material – to build homes according to the principles of circular economy that transcends the current approach of sustainability, in a global system that spans industries and borders. All of these advantages forecast concrete's vital mission in the establishment of the circular economic future, including some elements that can already be realised, such as:

- **planned reusing:** the components of lightly disassembled buildings made of concrete elements that can be – subsequent to their partial or full demolition – can result in their value-added reuse.
- **durability:** concrete buildings have a longer life cycle as they have a longer work life , lower maintenance requirements and a higher resistance against environmental impacts and throughout their life cycle, thanks to their repeated reuse, they require less demolition and reconstruction work, while the demolition materials can be recycled after treatment.
- **fire resistance:** improves the safety of residents and fire-fighters while minimizing damages, thus the building can be restored to its original function at a faster rate.

- **healthy buildings:** thanks to the natural components of concrete, it has features (sound proofing, it isn't a source of volatile organic compounds, it provides protection against radiation, etc.) that establish a healthier living space.

- **heating element:** when combined with 2D materials (e.g. graphene) indoor and outdoor heating panels can be produced.

- **passive heating:** as a result of its heat sink and heat storage properties, it allows for the passive cooling of buildings, thus reducing overheating and cooling needs.

- **surface:** with modern technologies a number of – even coloured or patterned – surfaces can be created that require no further casing, thus reducing the use of materials and maintenance requirements.

- **reducing environmental impact:** utilising the co-processing capacity of cement manufacturing can greatly reduce the need for fossil fuels, while the inorganic material content of waste is incorporated into the clinker, thus reducing the mined raw material requirement, while the co-processing of waste entails no additional environmental burden, as opposed to incineration plants.

- **the development of concrete technology:** modern concrete allows creating leaner structures, thus reducing the need for materials.

We must also emphasize that lower CO_2 emissions are projected for the life cycle of concrete than most other construction materials, such as wood (particularly glued, laminated timber), steel. Its versatile, flexible application, safety and durability clearly support the competitive advantage of concrete, whilst 100 percent of the material can be reused at the end of its life cycle.

As demonstrated above, as a result of the developments realized in the cement and concrete industry and its future improvements, it can come closer to realizing a carbon neutral future, yet beyond its own resources, this will also require innovation spanning multiple industries. The sector is striving for real experimental projects, such as:

- CO_2 capture technologies,

- oxygen factory project (CO_2 gas emissions enhancement),

- the development of new, non-hydraulic binders,

- clinker burned with less limestone and clay, at a lower temperature,

- innovative cement production process,

- concrete systems based on low CO_2 binders,

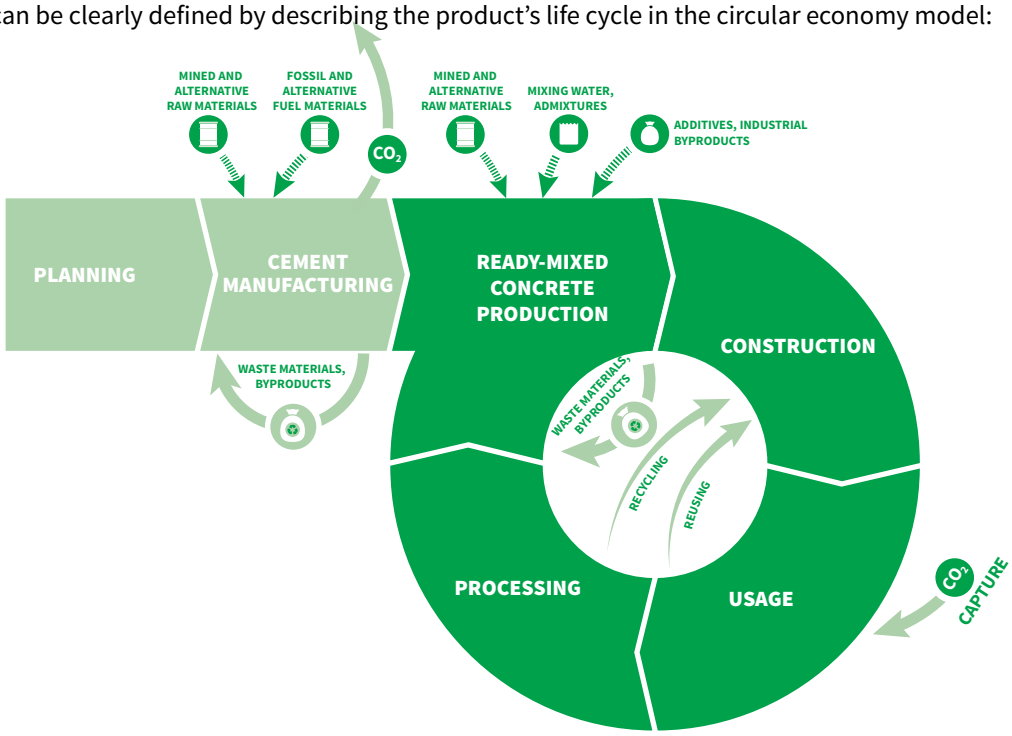
- developing oxygen technology that uses pure oxygen combined with high CO_2 concentration waste gasses during the recirculation,

- capturing the CO_2 produced during the production of cement with vegetation, reusing or transporting it to a storage site.

8. THE TASKS OF THE CONCRETE INDUSTRY AND REGULATION

The Circular Economy Model of Concrete

As an innovative industry, thanks to the continuous progress of the recent decades, a great deal of developments were realised, are underway or are in an experimental phase in the cement and concrete industry that support the circular economy model. Thus without this industry – since after water, concrete is the second most frequently used material on Earth – the implementation of the circular economy is unimaginable. The role of the cement and concrete industry in the circular economy model can be clearly defined by describing the product's life cycle in the circular economy model:



The goal is ensuring that production is free of waste materials that require further treatment, (which is now feasible) and making it carbon neutral by using a minimum of mined natural resources (challenges of the present and future) and that its life cycle is as long as possible as well as making it 100 percent recyclable by the end of the cycle (technically feasible). The production of concrete already allows for assuming numerous alternative raw, fuel and supplementary materials from the byproducts of other industries as well as industrial and communal waste products. The CO_2 emissions of cement production entail an environmental burden, yet it's capable of capturing a significant amount of CO_2 throughout its work life. The challenge of the future is to reduce or reverse the balance of the CO_2 emissions projected for the entire life cycle minus utilisation and capture, (so concrete would capture more CO_2 throughout its work life or the process would utilise more than is produced through its production).

In themselves, the efforts of the cement and concrete industry and its solutions spanning industries (for which we can now see numerous examples in the form of bilateral relations) are not enough to establish a circular economy. This requires political will as well as the indispensible establishment of a well-functioning regulatory system that ensures an effectively functioning system of the circular economy spanning industries and regions/national borders.

Regulations that integrate the cement and concrete industry into the circular economy model

a. **Co-processing of waste:** The harmful environmental impact of fossil fuels makes it even more important to increase the usage of alternative fuel and raw materials. Factories have introduced major developments to adapt cement production technology to this goal. The firing of suitably prepared waste materials of the appropriate quality is a cement production technology solution that results in the reduced use of fuel and raw materials without influencing the quality of the product and resulting in no excess environmental burden. Incorporating alternative raw and fuel materials into this process can be a solution for industrial and communal waste disposal issues. However, this requires the adaption of the cement industry to the waste management hierarchy in relation to the simultaneous combination of energy recovery and mineral reuse. The seasonal demand of the cement industry is converse to that of thermal power plants, therefore the two industries – when suitably coordinated – can accommodate waste materials all year long. Achieving the objectives related to reuse requires estimating the ratio of municipal solid waste devoted to co-processing and equal competitive conditions must be provided in relation to biomass waste usage. Suitable quality control procedures must be developed in relation to the admissibility of the material, its traceability and impact assessment.

b. **Supporting the application of innovation technologies with low CO_2 emissions.**

c. **Investment safety and the necessary economic framework** are preconditions for applying innovative, low CO_2 emission technologies within the European Union, therefore it's important to provide for the long-term prevention of carbon leaks (the relocation of energy-intensive industries to countries with more lenient emission limits).

d. Supporting **CO_2 capture**, storage and reuse, developing an international regulatory framework in cooperation with the industry, establishing professional trainings for the sake of social acceptance, informing the population and stakeholders.

e. The optimal infrastructure for **CO_2 supply networks** and secure storage sites must be fine-tuned on the regional, national and international level, e.g. the harmonisation of the United Nations Framework Convention and the identification of safe sites, the continuous operation, maintenance and inspection of continuous CO_2 storage.

f. **Supporting the effective use of clinker and reducing the cement/clinker ratio.**

g. The IPCC (Intergovernmental Panel on Climate Change) stated the phenomenon of carbonation and countries must apply a suitable global methodology for the **accounting of carbon-dioxide** in order to calculate the average net discharge of the total amount of cement.

h. **Supporting the work of the European Committee for Standardisation (CEN)** in reference to developing harmonised standards for cement and concrete (as well as its raw materials, components and additives), which allow the wide-scale application of innovative cements, while also ensuring the product's reliability, safety and durability.

i. In accordance with the Decree on Construction Products, the sustainability standards and regulations must be reviewed, **highlighting carbon neutral materials** and the entire life cycle of the building (and not its individual components). The built environment should attain carbon neutrality throughout its entire life cycle.

j. Utilizing the advantages of thermal heat flows **when designing smart and carbon neutral electricity networks and building stocks.**

k. Facilitating the **access to raw materials and encouraging the recycling of waste and byproducts.**

l. **Establishing a system for monitoring construction materials** throughout the entire value chain.

m. **Highlighting cements with suitably low clinker content** in the case of public procurement procedures and major investments.

n. Instead of focusing on the carbon footprint of cement and concrete, **applying the life cycle approach in the circular economy model.**

o. Supporting **clean energy investments**, ensuring flexibility for local energy networks.

p. Throughout all fields of the value chain, **the training** of architects, engineers and entrepreneurs on the effective use of cement and concrete is a key priority.

q. On the national level, reducing the energy consumption of buildings must be ensured through the execution of the **energy performance of buildings directive** (EPBD) as early as in the design phase, including the energy efficiency of thermal heat flow and the carbon neutral energy network.

Establishing an effectively functioning circular economy system is unimaginable – beyond the efforts of the industry – without:

- the adaption of the cement industry to the waste management hierarchy,

- the implementation of CO_2 capture and storage, transport and recycling,

- the establishment of a system for monitoring construction materials,

- standardisation that supports innovative technologies and

- a competitive regulatory environment.

9. WAY TO THE FUTURE

Our journal's motto: "Concrete – it's up to us what we create with it." Its production and the structures and infrastructures it uses have underwent and continue to undergo enormous technological development. Apart from technological developments, the energy efficiency renovation of service units must also be given top priority, achieving ever-stricter demands, staying ahead of the regulatory curve. For a long time, concrete was merely considered a material that is kept out of sight of the superficial observer and used only for foundation works or the support structure, yet architects now also use it as a design element on buildings. Industry 4.0 is also present within the industry and in Dubai, we saw examples of how processing the data provided by chips embedded in concrete was used to monitor the processes taking place within the material. Yet one might also consider 3D printing, which a few years ago only involved printing smaller objects within laboratory conditions, followed by the printing of bigger elements and assembling them on site and finally the production of simpler, single-storey buildings. The first two storey house made with 3D printing was produced in Westerlo (Belgium), eight meters in height and with a floor area of 90 m^2. The entire building was printed in full on site, without any mould, saving approx. 60 percent of the material, time and costs compared to convention construction techniques. The entire house can be printed within two days and the full construction time is only three weeks. The technology allowed eliminating thermal bridges, resulting in a low energy use building incorporating modern technologies, including the heating/cooling of the floors and ceiling, special solar panels, a heat pump as well as a green roof.

As demonstrated above, as a result of the R&D activities of the cement and concrete industry, incorporating concrete into the circular economy is realistic as it is a fully reusable construction material that can utilise numerous industrial and communal waste products and byproducts in its manufacturing. The industry is prepared for a carbon neutral future and we saw developments that allow improving the CO_2 balance (emission – sink), yet the R&D results of CO_2 utilisation outside of the industry are also promising. This will require the technological separation of CO_2 and making the existing gas and oil pipelines suitable for its transport, as its utilisation is/will be required in other industries.

The circular economy is a model that spans industries and national borders, thus in itself a single industry and its related regulation is not enough and there is still much to accomplish in the fields of the establishment and regulation of the economic environment, e.g.

- Facilitating selective demolition and selection carried out on the site where the waste is produced.
- The application of EU guidelines (pre-demolition survey, waste treatment protocol).
- The use of economic instruments for landfill diversion waste flows.
- Restricting landfill operations for activities that are in accordance with the definition of the Waste Framework Directive.
- Encouraging the use of products made of recycled materials through the application of quality certificates and the criteria of the end-of-waste status.
- Disseminating the practice of green public procurement procedures calling for recycled materials.
- Improving statistics with the use of up-to-date statements.

Circular Economy
Impossible mission or a realistic future?

The cement and concrete industry will do everything it takes to make it a reality.

The study was commissioned by the Presidency of the Hungarian Cement Concrete and Lime Association (CeMBeton)
and prepared by: Ferenc Urbán

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