VDB® INGENIERÍA CIRCULAR,

FROM THE LIFE CYCLE, TO CYCLES OF USE.

CIRCULAR ECONOMY

WITH A HELICAL APPROACH.

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Circular Economy, from theory to reality

It has become evident that the environmental crisis and climate change are worsening and accelerating, in large part, due to the Linear Economy model (extract – produce – waste), applied during the last two hundred years. This has generated that the current generations must act and promote urgent changes to our way of living and consuming, to face these challenges. In particular, the new generations of engineers must develop the necessary knowledge to achieve the objectives and values that the Circular Economy intends to incorporate into civil works projects.

There are economic and geopolitical impediments that make it difficult to change the current system of economic development, but we see many opportunities to act in the field of engineering to make changes and lead by example. The purpose of this article is to show how the objectives of the Circular Economy can be achieved, as the most valued alternative to face the new challenges. Our company has a lot of experience to share and the power to develop these new projects, with sustainability as its central axis.

The Circular Economy is based on the cyclical feedback of fundamental steps, such as: reduce waste, recycle materials, and reuse components. Over time, this sequence has been defined in greater depth, arriving at a cyclical model like the one below, which consists of eight phases:

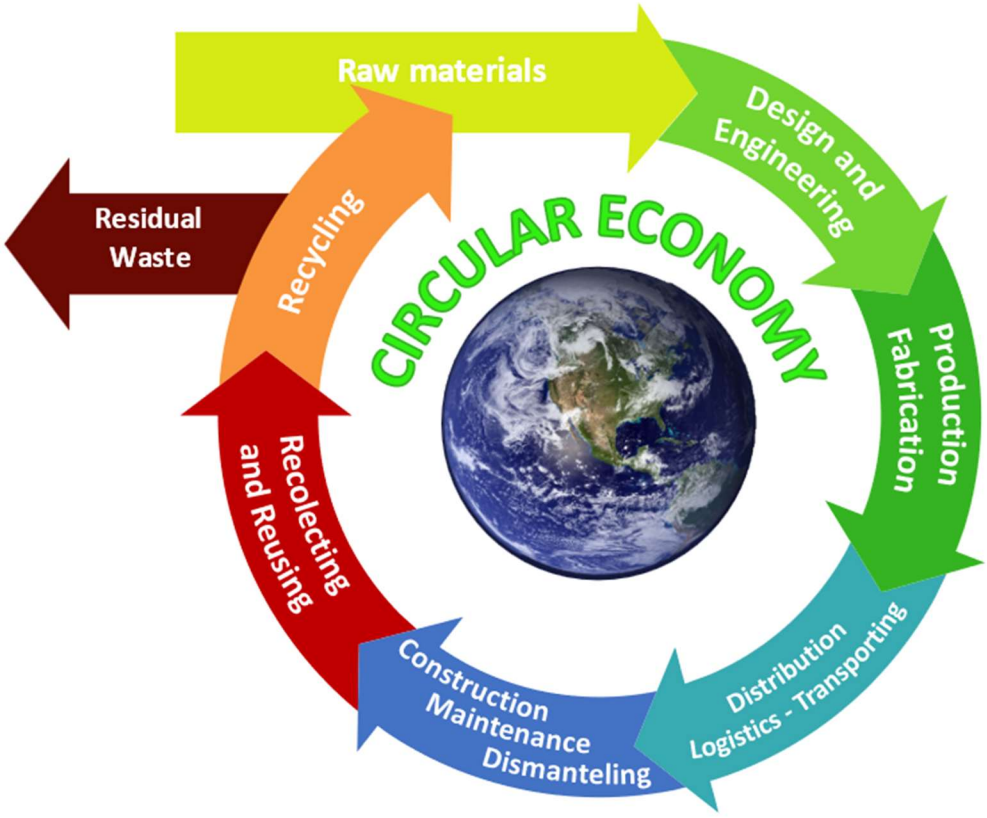


Image 1: Circular Economy in 8 phases

As can be seen in the Circular Economy diagram (Image 1), it has phases that are related and dependent on each other. That is why the realization of a single phase by itself will not provide the sustainability benefits that the model proposes. Strictly speaking, the circular model requires that each of the phases be executed to achieve the objectives of reuse over time. Thematic aspects that are part of the different phases are:

- **Design**: from the beginning it should be considered that there is a circular analysis and definition that allows the product, structure, and its components to have the economic, technical, and logistical feasibility so that it can go through all the stages of the model more than once. It is Reverse Engineering that meets provides us with these design criteria.
- **Initial production**: which requires that it be from an industry with sustainable and green processes, with non-polluting renewable energy and without the generation of waste or environmental liabilities.
- **Cyclical reworking**: for existing prefabricated products and elements, these must be reconditioned to keep them in use and retain their value or even increase it.
- **Distribution**: it must be generated by non-polluting renewable electrical energy.
- **Consumption, Use**: it must be done in a way that allows maintenance, repairs, and cycles of use of the elements for extended times.
- **Reuse**: because of changes in the needs of society, it is necessary to generate cycles of use and not design for a single life cycle.
- **Repair**: it will allow the structures, products, and elements to spend the greatest amount of time in this phase.
- **Collection**: must be done by using non-polluting renewable electrical energy.
- **Recycling**: This allows products and materials to continue to be in use, generating new raw materials, thus reducing, and eliminating waste.
- **Residual Waste**: Traceability of raw materials must be generated in the designs; ensuring that after a period it is possible to reduce waste and eliminate environmental liabilities. Thus, complying with legal requirements and taking advantage of state incentives for such purposes.

Undoubtedly, all the above points contain challenging aspects, since new knowledge, investments in technology and expert professionals are required to achieve the full cycle of the Circular Economy. This can lead to reticence from some companies, product of the investments needed in required innovations; however, from the economic point of view, this will allow, over time, the possibility of developing businesses with greater profitability than the current ones, given the divergence of services and by-products at each stage of the Circular Economy, thus increasing the labor market, and associated technological development.

The Circular Economy made up of companies and people

The Circular Economy is a model and a means to achieve the objective of not generating waste. Applied to the construction market and more specifically to the realization of products and structures in reinforced concrete, many specialized companies and professions that make up the value chain can be identified in each activity and are shown in the following figure:

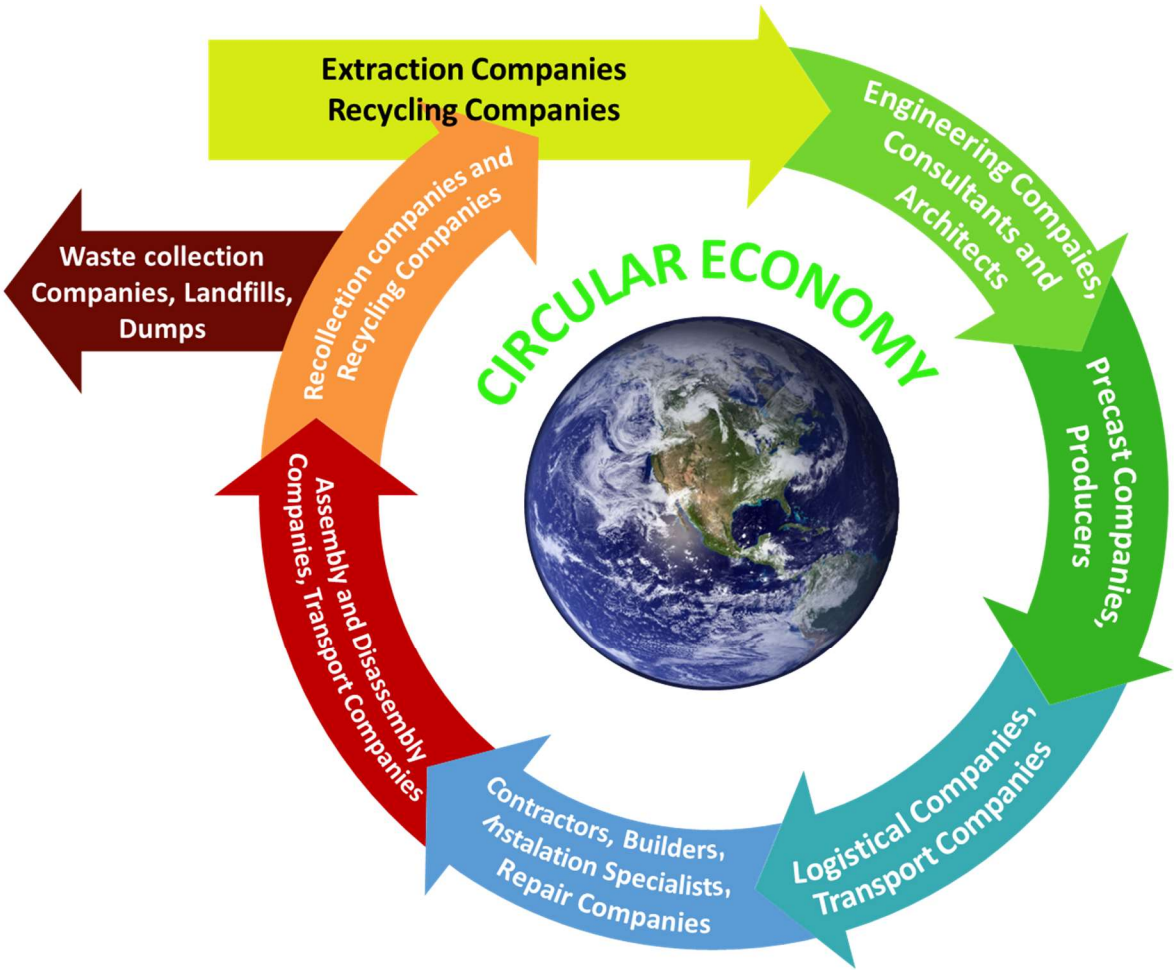
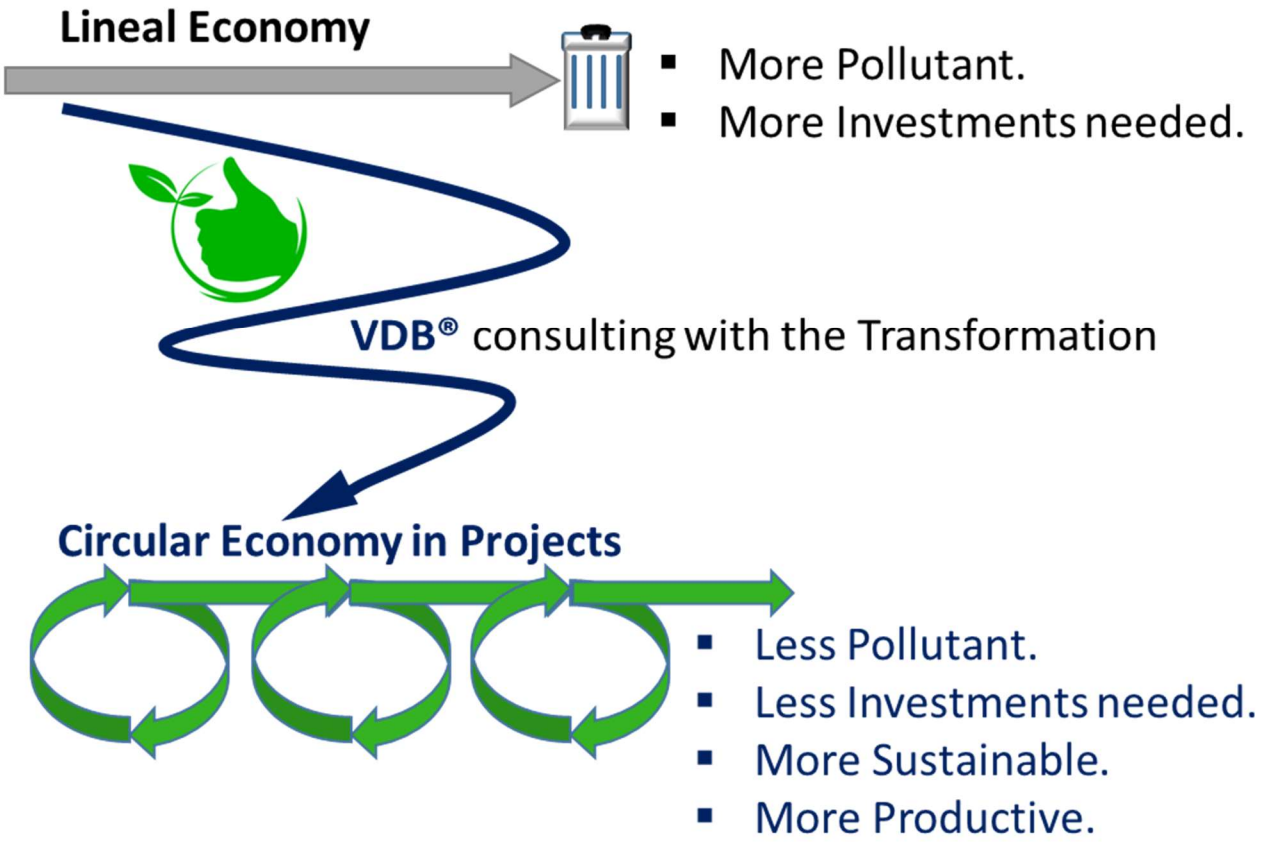


Image 2: Companies and Professions that make up Circular Construction

The company **VDB® Ingeniería Circular** (VDB Circular Engineering) is working to accompany its clients on the path of transforming their projects from the Linear Economy to the new Circular Economy. Generating the structure of communication, coordination and planning required between all the actors involved in the entire value chain, in modular solutions with Prefabricated Elements in reinforced concrete, from the Engineering stage of the first use, the stage of the second use, until the stage related to the recycling processes.

VDB® Transforming Projects from lineal to circular:



Use of the Circular Economy

The Circular Economy is a model and a means to achieve the objectives of not generating waste. In any Economy, diverse activities are related between different companies, professionals and people who contribute with their knowledge and specialization. Markets that group activities such as agriculture, construction, mining, aeronautics, energy, or the port, require specific techniques and specialized professionals, but they also know that each of them is related to another in order to function. Linkage and cooperation between markets is essential for a country to develop and generate well-being for its inhabitants.

The image shown on page 2 provides a captivating vision of circularity and the concepts of reuse and recycling, but it is only a starting point for each person, company, industry, market, and country. With the identification of the objectives to reduce and/or eliminate waste, and the incorporation of the traceability of raw materials in the stages of recycling and reuse in the projects; each person must generate their real version of the use of circular knowledge for their profession, products, niches, and markets.

At **VDB® Ingeniería Circular** (VDB Circular Engineering) we are aware that at each stage of the Circular Economy we are generating waste and various types of Greenhouse Gases (GHG). Our carbon footprint, measured through the tons of CO_2 generated, is just one of the GHGs. Image 3 summarizes the aspects that we must bear in mind at each stage of the specialized work that contributes to circularity, and that allows the reduction of Waste and GHG.

Image 3: Circular Economy in 8 parts with creation of Waste and GHG

Use Cycles instead of Life Cycle

Both climate change and current environmental problems, added to the strong population growth worldwide, make us think that civil structures should be designed for more than one use and that they should not generate environmental liabilities. It is therefore that in this document the concept is promoted that every material or product made has several Cycles of Use and not a single Life Cycle, because this last concept preconceives that a product or material will be a waste in the future, which is a single semantic aspect since currently there are the necessary technological advances to prevent a product from finally being a waste in its entirety.

In the specialty of our material, which concerns the use of concrete, it is already very evident that well-designed structures in a modular way and using Prefabricated Elements allow more than one use. Conventional concrete, with cement, or geopolymeric concrete, are materials that can last for decades; As an example of this we can cite the "Pantheon" building in Rome - Italy, made of non-reinforced concrete, located in a seismic country, which has stood for 2000 years.

To generate the new design criteria that incorporate the objectives of the Circular Economy, to reduce and/or eliminate waste, strengthen the capacity of structures to be recycled and generate that the works have the possibility of having more than one use, we must make use of the Reverse Engineering method. The percentages allowed by the owner or investor in concrete civil works, for environmental liabilities and/or waste, recycling of their work and reuse of modular Prefabricated Elements, is something basic and part of the definition of design criteria. Additionally, knowledge about constructability, productivity, execution, transportation, production, and molds must be incorporated to have them in the list of data to start the designs, architecture, and structural engineering.

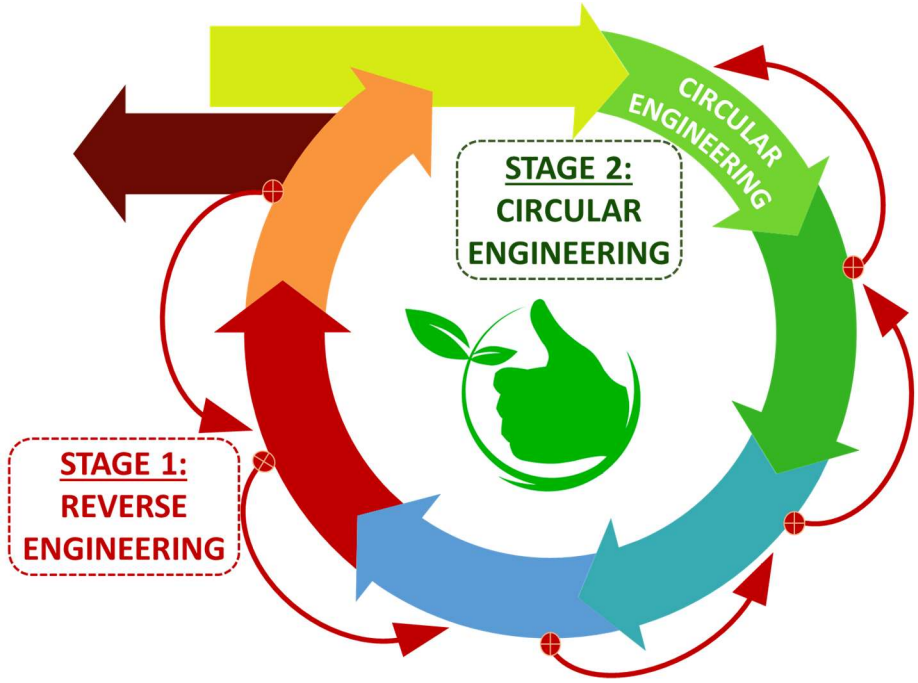


Image 4: Stage 1 Reverse Engineering before Stage 2 Circular Engineering

To reach circularity requires a systemic change in the way we do Engineering, knowing that 80% of circular results are obtained from design. For this reason, it is key to add new knowledge to the processes for defining Design and Engineering criteria.

The Circular Economy will be motivating for each new generation of professionals since it represents possibilities to generate additional reductions in the use of resources. This, combined with sustainable production and execution of modular concrete structures, will allow structures to be obtained with fewer resources, keeping existing products and Prefabricated Elements longer in use.

At **VDB® Ingeniería Circular** (VDB Circular Engineering) we generate a significant impact on the use of resources by allowing customers to reuse materials, products, Prefabricated Elements, and complete structures, thus mitigating climate change. We have green alternatives for the construction industry that are more environmentally friendly products and services. We create value that goes beyond direct short-term economic benefit.

The depreciation of value of concrete structures must be completely abandoned and replaced by a new and more realistic methodology. We do not have structures with a value of 0 US$. Over time, the Renewable Prefabricated Elements that are going to be reused maintain their value and reduce the need to use new raw materials. All the parts of the concrete structures, which in recycling processes generate scrap (steel) and aggregates (crushed concrete), have a value as new recycled raw material, which reduces the need to extract new ones. Traditional waste has an associated cost to be treated, deposited, or eliminated, which must be considered from the beginning to be included in the financial study of the investment.

TABLE VDB-1 – DESIGN OF STRUCTURES WITH 3R TRACEBILITY IN TIME

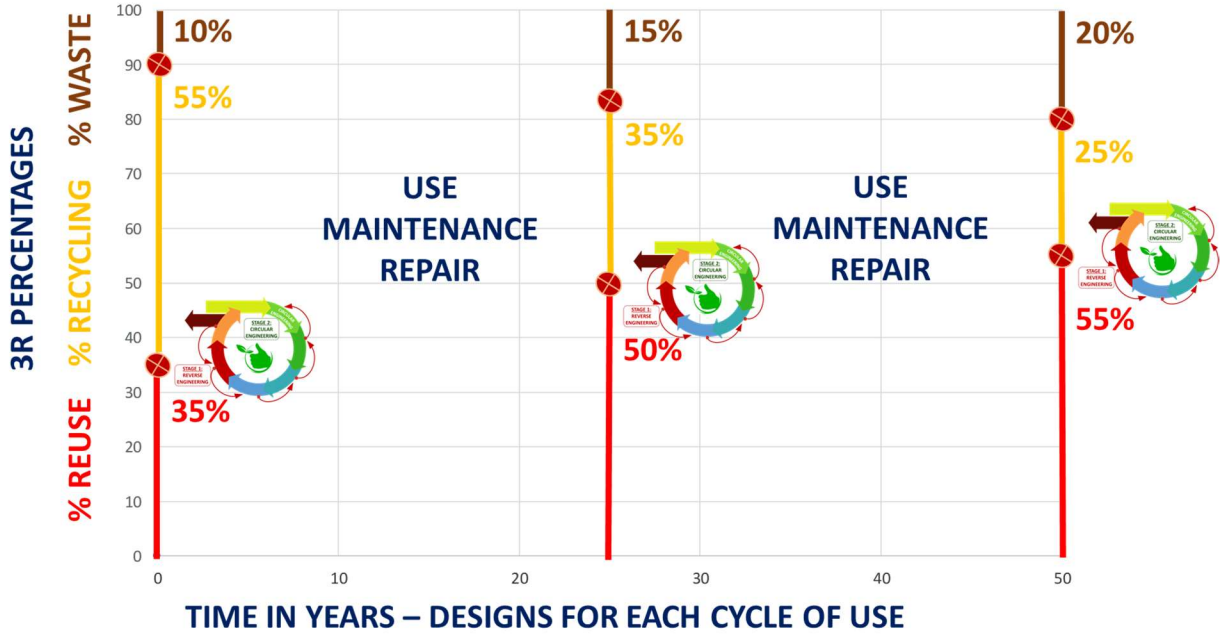


Table VDB-1 (on page 8) shows the traceability of how, over a period of 50 years, a modular and prefabricated concrete structure can have different uses or be assembled and disassembled in different places. The percentages of reuse, recycling and waste allow each task to be completed with the economic values, allowing the traceability of the value of each good in the principal's accounting.

Circular Economy in projects

The construction industry is responsible for approximately 38% of the generation of Greenhouse Gases (GHG) worldwide, so it is and will be the duty of societies to incorporate this market into a more sustainable model such as that of the Circular Economy. For example, a model analogous to the one discussed above is required, but with its own circular phases that cater to construction projects of all kinds, which in turn have their own characteristics that differentiate them compared to common consumer products.

Among the characteristics of the linear projects of Civil Works in concrete, the following can be mentioned:

- Projects are often unique due to their use, shape, location, and materials.
- They are important and unique investments.
- They are unique in design.
- They have a unique way of being constructed.
- They are currently designed only for one Life Cycle.

All the points mentioned do not limit the capacity of Engineers to generate new circular solutions that allow a modularization of concrete works using Prefabricated Elements and that tend to:

- Standardization of parts and Prefabricated Elements.
- Reusable and recyclable materials.
- Solutions that maintain their value due to the quality of their design, production, and assembly.
- Unique projects, but mountable and removable.
- Modern, mechanized, automated and robotic execution methods.
- Projects and structures made for the reuse of several Cycles of Use.

In the philosophy of **VDB® Ingeniería Circular** (VDB Circular Engineering), the reuse of civil works in concrete is possible on a large scale and this means that the stage of recycling raw materials is the last step after decades of use. As concrete and steel are recyclable materials, it must be ensured that concrete waste from the construction market is eliminated completely and does not end up in landfills.

The following images (from 5 to 8) show, for the construction industry, the cycles of use of structures. In image No. 5, the circular parts that make up the first use generate a cycle that contemplates the stages of use, maintenance, and repair in a single color (blue).

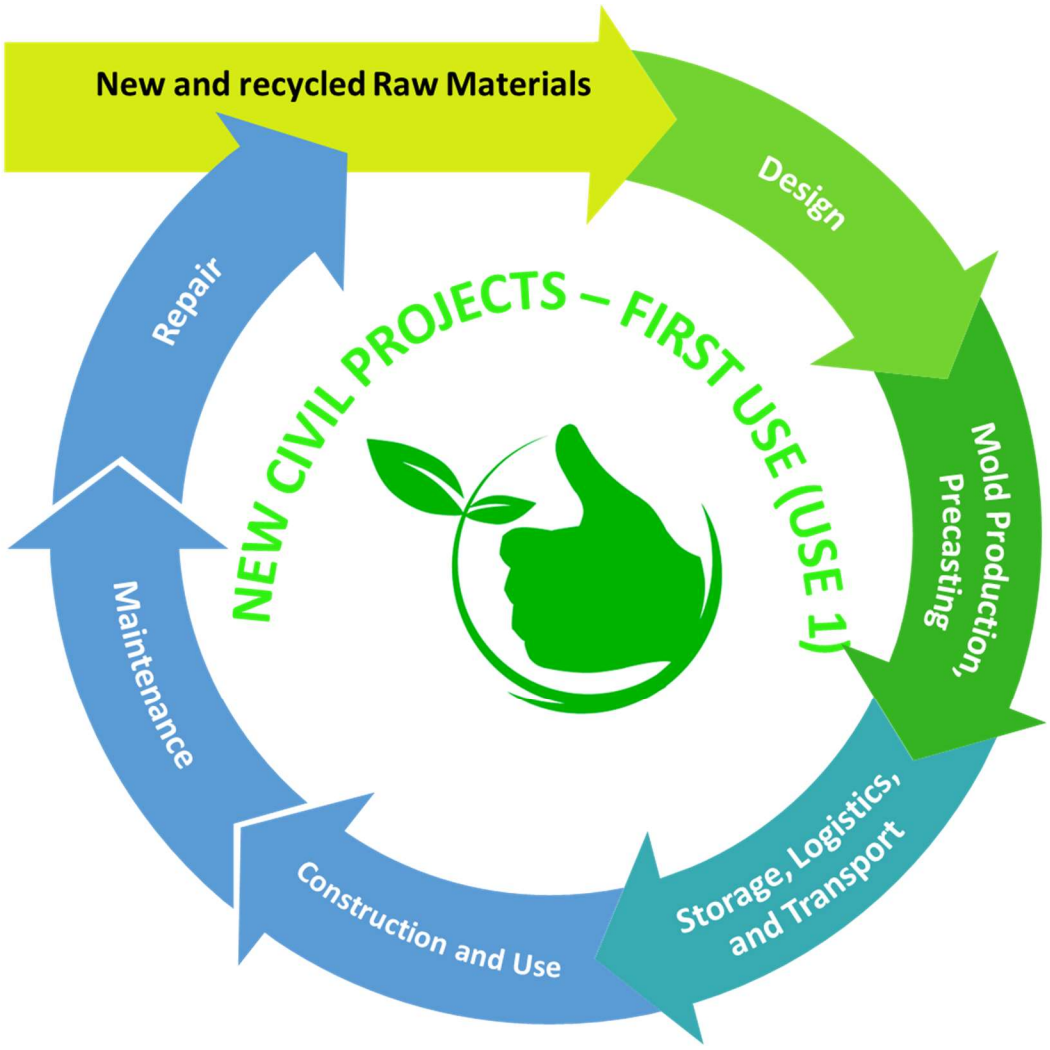


Image 5: First Cycle of Use of New Civil Works in concrete

Image No. 6 shows that each Cycle of Use is a circle by itself. A technical continuity of the structure over time implies that each Cycle of Use has its own work related to the redesign of Elements and parts and the generation of documentation that attends to the disassembly, collection of Elements and Materials and generation of raw materials based on recycling.

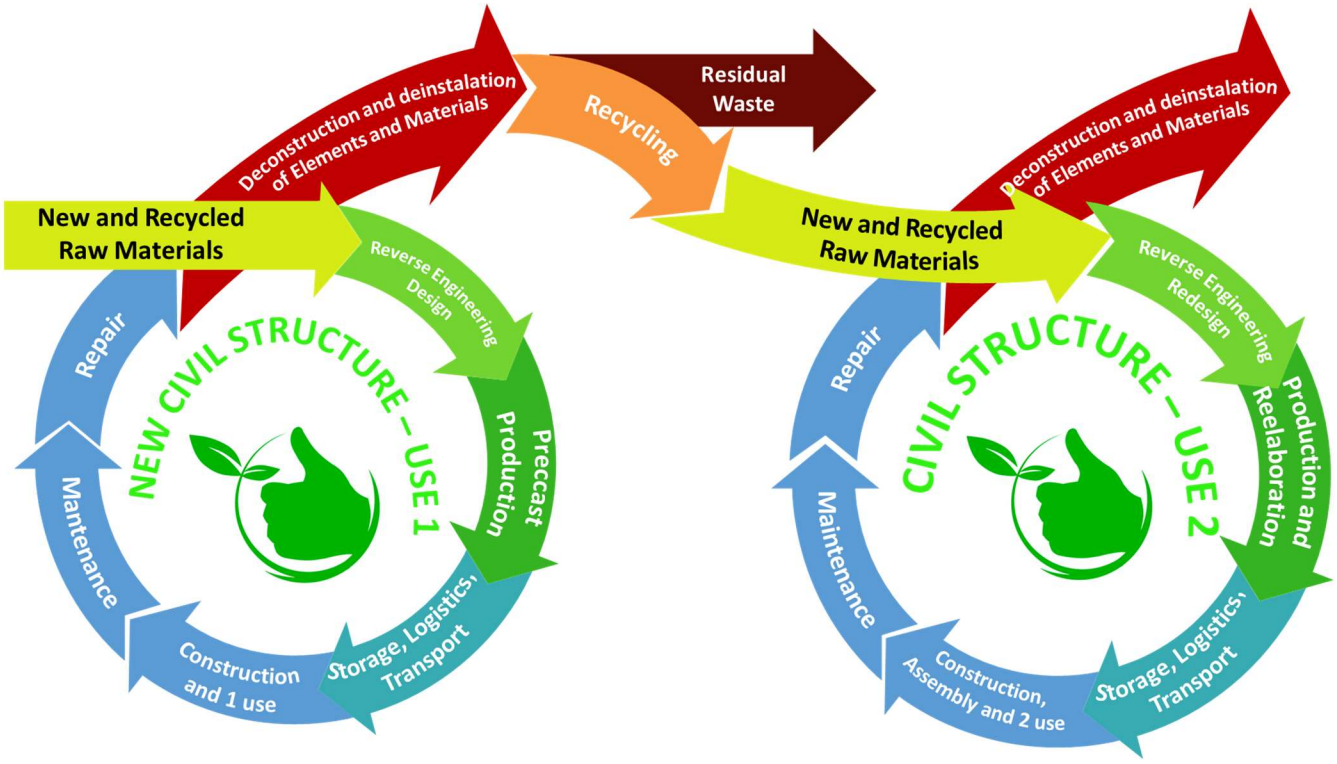


Image 6: First and Second Cycle of Use of Civil Works in concrete

The above aspects generate a continuous and cyclical reuse of materials over time. Each use generates a circular cycle by itself, and this continuum as a whole resembles a helical movement in time. Each cycle generates knowledge that will serve for the next cycle. Thus, the technical characteristics of the works, added to the cycles of use and the values of the Circular Economy, lead to represent the development of the projects through the following scheme:

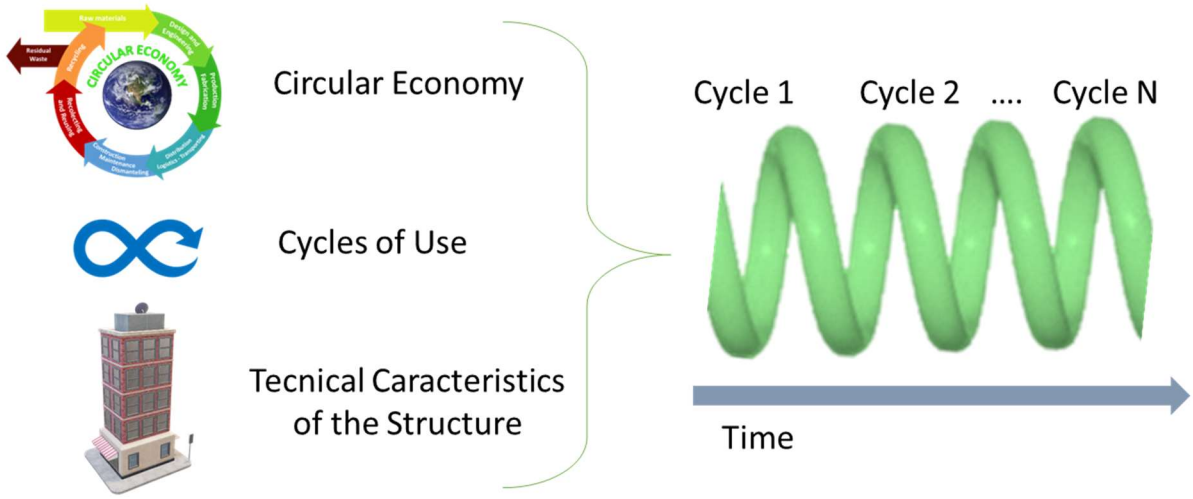


Image 7: Content of the projects in the Helicoidal Diagram of the Circular Economy

Evidently, the previous model is more beneficial, from the economic and environmental point of view to the extent that a cycle lasts longer (use with maintenance and repair) and that it has a greater number of cycles of use and reuse. It is likely that for projects of modular concrete structures, the reuse of more than 2 cycles may seem ambitious; however, it must be borne in mind that each phase will be very long-lasting, due to the strength and durability of the materials involved.

The new design criteria must generate buildings and projects that, from the outset (engineering conception and design), contemplate multiple uses. For example, design buildings that contemplate a first use as offices, but that already have all the technical and functional aspects incorporated to be able to be changed to residential use. The direct benefits of these designs are among others:

- Reduction of environmental liabilities.
- Reduction in the generation of Greenhouse Gases.
- Reduction of CAPEX investment costs.
- Real alternative to shortage of raw materials for construction.
- Contributions to social problems such as: shortage of residential buildings and shortage of educational structures.
- New contributions from the professions in the construction value chain to society.

Below is an ideal theoretical diagram in which the cyclical flow of a construction project is proposed:

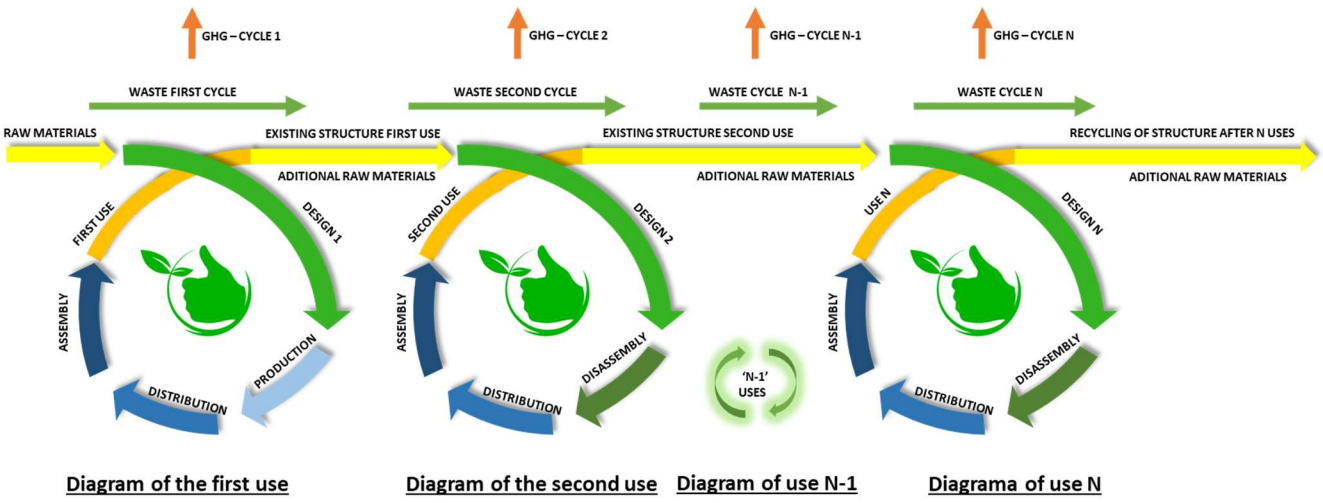


Image 8: Projects over Time in the Helicoidal Diagram of the Circular Economy

In the diagram above, a new sequence of the Circular Economy is proposed to address Engineering and Construction projects; it incorporates the following concepts:

- It is considered dynamic in time because it is in a relative movement depending on the cycles of use, it is possible to visualize it in 3D as a helicoid.
- Design of projects, based on industrialized modular systems, the latter to guarantee greater quality and durability of materials compared to traditional construction.
- Production in industrial areas or plants; this has the benefit of incorporating renewable energy, waste reduction, elimination of environmental liabilities and to have jobs in areas close to where workers and professionals live.
- Logistics processes with digital data tracking for the distribution of Prefabricated Elements to assembly sites.
- Assembly of Prefabricated Elements, in modular solutions, which allows a significant reduction in the number of personnel on site and, consequently, reduces the amount of waste on site. On a technical level, being able to assemble and disassemble structures allows significant reuse of its Precast concrete elements, resulting in renewable investments.
- The choice of materials for each cycle, due to their ability to be recycled and reused as raw material, is key. Reinforced concrete is 100% recyclable.

A helical approach to the Circular Economy for Construction

Incorporating a helical approach in the Circular Economy is important because it enhances the use cycles of concrete structures. The new projects with assembly and disassembly cycles provide savings in the initial investment, eliminate the amortization of concrete works, generate income for reuse stages, income from the sale of recycled materials and significantly reduce environmental liabilities. The reduction of environmental liabilities; For example, in mining, it is feasible and allows reducing the enormous financial expenses that the Mine Closure Law generates for investors in Chile.

The helical shape is in our DNA and therefore easy to remember. It is our nature to thrive with the helical shape and in our DNA we have it double. The Circular Economy is in our blood.

Image 9: The Evolution of the Circular Economy to the Helical Approach is in our DNA

Prefabricated concrete elements with multiple uses

Decades of development and innovation have been invested in the construction industry to contribute and achieve sustainable objectives, which come with the implementation of Use Cycles in the designs, production, and execution of these works. For new modular structures, special joints are used between the Precast Elements, which allow them to be assembled and disassembled a greater number of times.

For existing structures, studies and research must be carried out to do the redesign that incorporates the sequences of disassembly and deconstruction of said structures. Deconstruct is the way of specifying the work of breaking up wet joints (done with cast-in-place concrete) and releasing parts of structures to be moved to centers for repair, modification, and preparation for their next use.

To achieve the designs more efficiently, with the values and objectives of the Circular Economy for projects, it was necessary to categorize the different types of Prefabricated Elements that make up a structure. In **VDB® Ingeniería Circular** (VDB Circular Engineering), the categorization of modular reinforced concrete elements into 4 types has been promoted, which depend on their types of links or joints and, above all, their level of specialization in design, as shown in the following diagram:

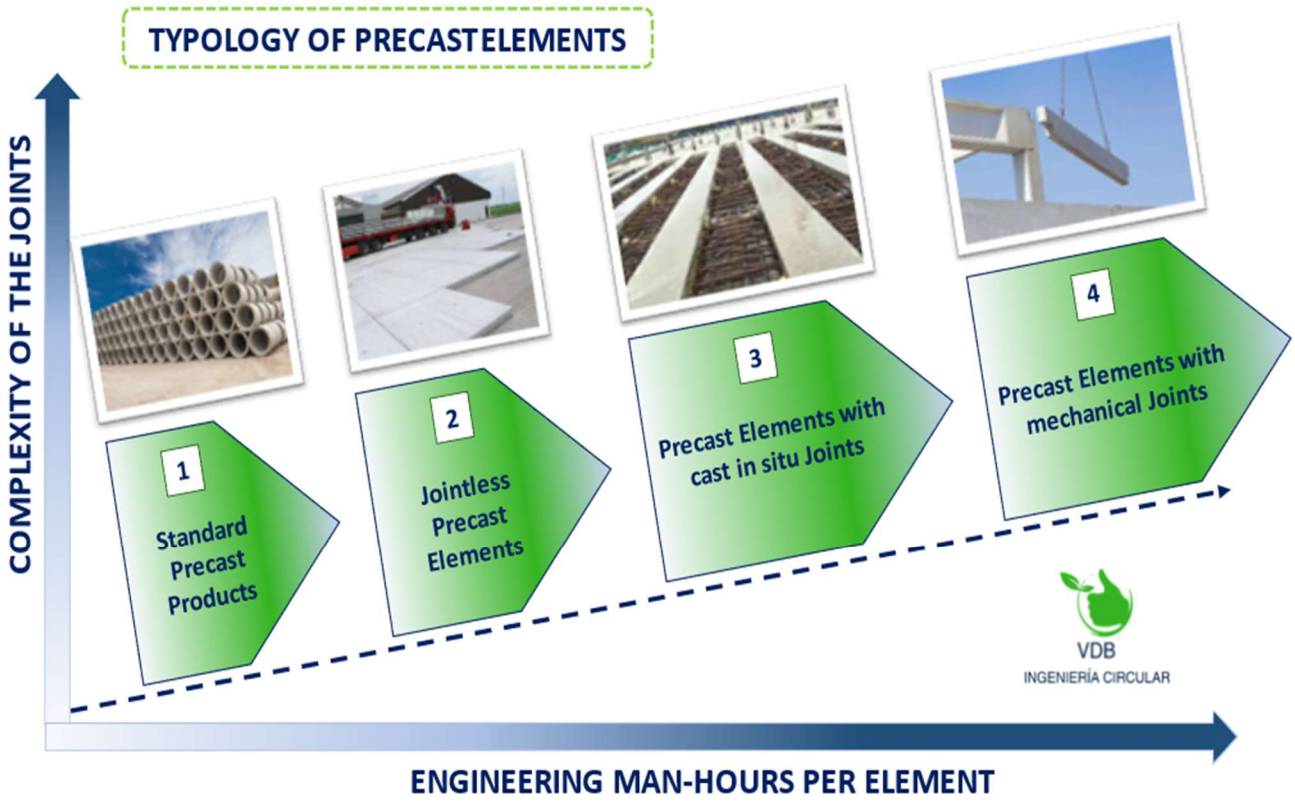


Image 10: Types 1 to 4 of Prefabricated Concrete Elements

If a structure is made with Type 4 Prefabricated Elements, with mechanical, bolted, or post-tensioned joints, it has a clear advantage from the beginning to be disassembled and reused in another location, since the joints are dry and are easier to remove, extending the number of use cycles to many more than one.

Type 2 manufactured elements, with butt joints, are very versatile and have different cycles of use. In image 10, you can see a system with square precast panels to generate permanent or temporary industrial pavements. Thus, a pavement for buses in a mining project can be lifted up, taken out and transported to a coastal port area to create an extension of a storage area for bulk materials.

The Circular Economy, with cycles of uses in construction, is the fastest and safest way to implement and achieve the sustainability objectives that we need to combat climate change and generate good contributions for future generations.

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Glossary

Sustainability - In ecology, sustainability describes how biological systems remain productive over time. It refers to the balance of a species with the resources of its environment. In construction, the noble material of reinforced concrete does not need to generate waste because it can be kept in the environment and be reused or recycled repeatedly. Crushed concrete generates new aggregates and steel bars become scrap to enter a new cycle to produce steel.

Environmental Liability - The concept of Environmental Liability can be defined as that environmental situation that were generated by man in the past or in the present and future, that can generate a progressive deterioration of this situation over time, representing a risk to the environment and the quality of life of people at present and/or in the future. For example, a reinforced concrete structure left abandoned on a site that can remain there for centuries and/or collapse over time.

Residual Waste - The word residue (from the Latin ¨*residuum*¨) describes a material that loses its usefulness after having fulfilled its mission or having served to perform a certain job. Residual wastes are products and materials that cannot be reused or recycled at this time.

Renewable Investments - Generate investments in reinforced concrete civil works that over time continue to generate value for investors and owners. This is possible when the investment conditions stipulate the need for the presence of reuse, recycling, and generation of new raw materials in **a new way to manage Civil Engineering designs and engineering.** From early stages in the projects, it is necessary to generate the visualization of the economic values that concrete structures maintain after their first use.

Circular Economy - The Circular Economy aims to minimize the environmental impact of products, services and processes, this must be addressed from the early planning stages with a systemic approach. Thus, it seeks to eliminate waste, garbage, and pollution with intelligent and circular designs. Keep materials and products in cycles of use for as long as possible.

Linear Economy - The Linear Economy is the traditional model where to manufacture products raw materials are extracted, then it is produced and after its use it is discarded, without considering the environmental footprint and its consequences.

Greenhouse Gases (GHG) - A greenhouse gas is a gas that absorbs and emits radiation within the infrared range. This process is the fundamental cause of the greenhouse effect. The main GHGs in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Cycles of Use – The word cycle is derived from the Latin ¨*cyclus*¨, and this in turn from the Greek ¨*kyklus*¨ which means "circle or wheel". Cycles of Use are called the period in which a set of events, stages or phenomena are developed or occur that, once completed, are repeated in the same order from beginning to end.

Helical – It is used in this article to indicate the continuous circular movement in time that occurs when the different cycles of use of a concrete structure are developed. The helical movement displayed in the images in this article is a rototranslatory movement that results from combining a rotational movement around a given axis with a translational movement along that same axis; the result is a helical motion.

Table VDB-2 with the 4 Types of Prefabricated Elements and examples of their uses in different cycles over time.

Below, in the table, are examples of products and Prefabricated Elements of types 1, 2, 3 and 4 with ways they can be used in the first cycle of use, in the second cycle of use and in a third cycle of use. In the last column the indication of what can be done with the products after their 3 different types of use. In these post-use examples, concrete and reinforced concrete can be recycled to generate steel scrap and crushed aggregates.

Categorization VDB®	Description of the Elements	Function in its first use 1	Function in its second use 2	Function in its third use 3	After the varios use cycles
Type 1 Standard Elements	Standard concrete products and standard elements from a catalog	Concrete Cobblestones	Blocks for walls	Fences	Recycling
		Concrete Pipes	Water collectors	Landscaping	Recycling
		Prefabricated Collectors	Bridges	Collectors / Landscaping	Recycling
Type 2 Elements without joints	Industrial slabs	Temporary Road	Parking pavement	Retaining walls	Recycling (*)
	Prefabricated panels	Retaining Walls	Retaining walls	Pavement	Recycling
	Precast "L" shaped elements	Retaining walls for road project	Coastal retaining walls	Pavement	Recycling

Categorization VDB®	Description of the Elements	Function in its first use 1	Function in its second use 2	Function in its third use 3	After the varios use cycles
Type 3 Elements with cast in situ joints	Foundations	Foundations for Infrastructure	Industrial Foundations	Marine protection structures	Recycling
	Precast Beams	Infrastructure Beams	Industrial Beams	Residencial Columns	Recycling
	Pillars / Columns	Infrastructure Pillars	Industrial Pillars	Beams for rural bridges	Recycling
	Beams / Pillars / Foundations	Industrial sheds	Industrial cellar	Educational building	Recycling
Type 4 Elements with mechanical joints	Foundations	Infrastructure Foundations	Industrial Foundations	Marine Defense structures	Recycling (*)
	Precast Beams	Infrastructure Beams	Industrial Beams	Pillars for houses	Recycling (*)
	Pillars	Infrastructure Pillars	Industrial Pillars	Rural bridge beams	Recycling (*)
	Beams / Pillars / Foundations	Industrial Sheds / storage facilities	Industrial storage facilities	Educational Buildings	Recycling (*)

Note (*): Elements that probably can have even more than three cycles of use.

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