

POLITECNICO DI TORINO

Master's Degree in Architecture for Sustainability



HOW GREEN?

or

GREEN HOW?

**A Qualitative Evaluation
of Sustainable Architecture**

Master's Degree Thesis

Supervisor

Prof. Giacomo Chiesa

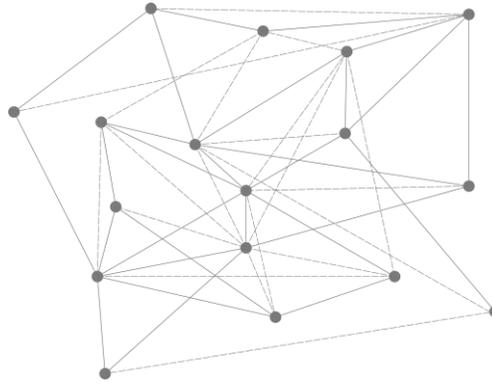
Co-supervisor

Prof. Marijke Steeman

Candidate

Diego Santa Maria

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ABSTRACT

Over the last few decades, the accelerating pace of technology has led to a profound colonization of nearly every aspect of contemporary life. As a result, architectural practice has adapted to deal with ever-growing amounts of data, where digital tools promise new levels of precision and efficiency. Appropriately framed, these instruments can be extraordinarily successful in contributing to effective designs that tackle the urgent factual challenges of global crises such as climate change, but remain uncertain under more complex humanistic dimensions of the Anthropocene. Within this panorama, this same dependence can lead us to navigate blindly through numbers that suggest clarity but often conceal fragmented or partial realities. Sustainable architecture has been repeatedly counseled as a key agent in this scenario, yet a consistent definition of its components remains fractured into visions and methods that communicate unclearly with one another.

The vast studies around sustainable architecture have built over its relatively recent history, some increasingly sophisticated approaches for prediction and evaluation. Nevertheless, the fragmentation of the discipline is partially driven by the increasing number of terms used indistinctly, despite their emergence in response to diverse contexts. Many of these tailored approaches end up favoring specific markets and praising certain dimensions of sustainability while marginalizing others. As a consequence, this positivist discourse often drives contemporary practice to operate through isolated fields that solely focus on their vision, while neglecting the systemic relationships that bind a wider understanding of sustainability.

This thesis takes such fragmentation as its starting point, conducting epistemological research aimed at establishing a shared foundation of what sustainable architecture can mean today. It critically examines the frameworks, indicators, and professional workflows through which sustainable architecture is commonly evaluated, questioning their assumptions, scope, and tendencies. By mapping correlations across disciplines and tracing the interrelations of the toolchains that now drive design practice, this work seeks to push beyond a performance-centered practice toward a critical, meaningful one, uncovering pathways for a more coherent, resilient, and ambitious sustainability, one capable not just of mitigating crises but of reimagining the role of architecture in shaping futures worth living.

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A mi madre, y su inquebrantable espalda por empujarme hasta aquí.
A mi padre, por sus consejos que me formaron en la persona que soy.
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alcanzando un sueño que podamos compartir.

Chapter 1

A Common Ground

“All is not well, but all is not lost, either.”

-Human Development

Report 2021/2022

1.1 Global Crises

In recent decades, humanity has faced a range of challenges, from concrete issues to more paradigmatic ones. Looking for a way to summarize XXI century tendencies might be pretty ambitious, but framing a common ground to start such a complex discussion as the contemporary role of architecture requires such effort, risking to obviate intricated topics, this first chapter will pursue placing on the table the main planetary crises that relate to architectural endeavor and its implications on different layers of reality, while gradually outlining the perspective from which this research takes form, one that questions how design can operate meaningfully within these intertwined conditions and what kind of architectural reasoning may be adequate to address them.

It is worth noting that, as a result of over-globalization and the tendency to view phenomena as intertwined systems, global crises have accumulated ^[1] and can no longer be treated as separate problems. On the contrary, the ongoing climate, financial, and food crises, as well as the repercussions of the COVID-19 pandemic, are interrelated and function as components of a larger macro-ecological system.

A. Factcities

It is evident to almost everyone that we have been experiencing rising temperatures year after year. These shifts are already shaping our daily lives, from how we dress to the way we plan our routines to where we seek comfort. Less visible but far more alarming are the increasing frequency and intensity of wildfires, storms, melting glaciers, sea-level rise, ocean acidification, desertification, and a devastating collapse in biodiversity, with over one million plant and animal species now facing extinction [1]. These are likewise crude reminders that there is a marching climate crisis that most of the projections presume will grow exponentially even if we stop adding pollutants to the atmosphere. There are many unstoppable processes that are set in motion beyond our control, ringing alarm bells from planetary systems increasingly out of balance [2].

Among the many cascading risks, the dramatic decline of pollinizing insects such as bees and butterflies stands out by threatening a chain reaction leading to a severe food and agricultural collapse that would affect, like the rest of the risks, the most vulnerable groups first and hardest, deepening the existing socio-economic inequalities. By now, it is just 20% of the world's population who have been responsible for more than 70% of global CO₂ emissions [3], highlighting not only an ecological but also a deep moral imbalance. The situation has never been clearer, with undeniable consequences ahead of us and strong evidence from hundreds of studies pointing in the same direction. These mostly quantifiable facts build together the factcities, or the conditions of existence we are forced to live with; these are the unmovable landmarks to begin building the reality within which this generation must now exist and act.

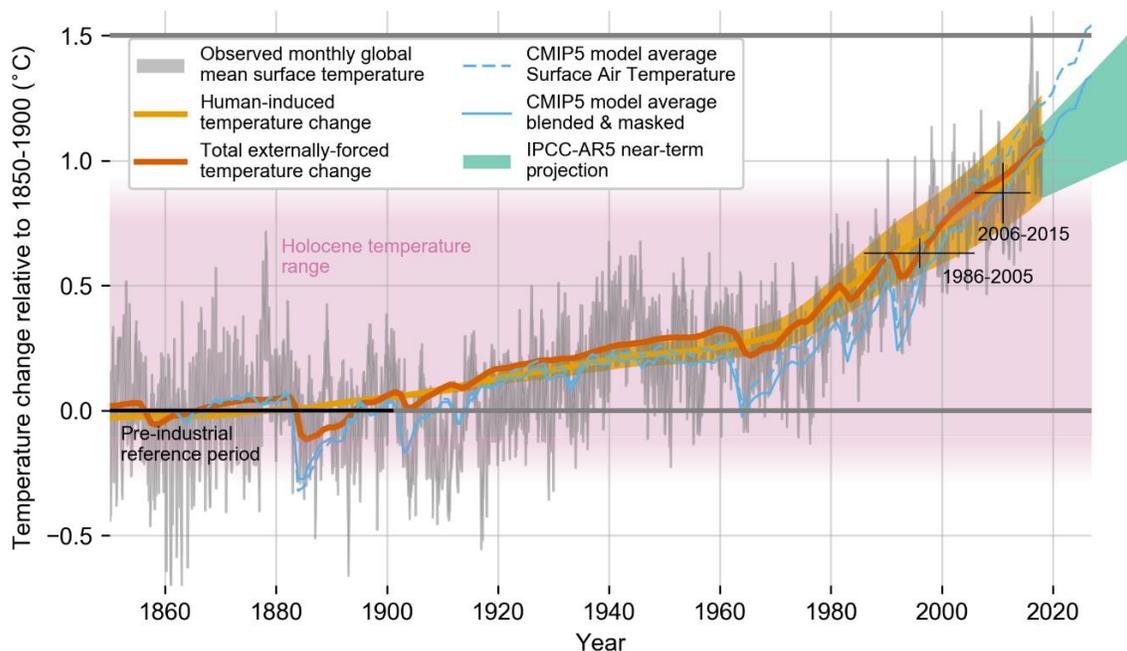


FIGURE 1.1.1 – Evolution of global mean surface temperature (GMST).

© IPCC. Summary for Policymakers. 2018

At the same time, the human civilization footprint has reached a symbolic threshold, the weight of man-made materials such as concrete, asphalt, and plastics now outweighs the entire biomass of the planet. Microplastics pervade water, air, and living organisms together with vast garbage islands floating across our oceans, some as large as entire countries. These are no longer isolated by-products but systemic symptoms of a crisis that threatens the survival of our species, yet we continue to perpetuate conditions that fuel the situation [4]. Reflecting the severity of the situation, the Intergovernmental Panel on Climate Change (IPCC) declared a “code red for humanity” in its latest synthesis report, marking a critical juncture in the fight to prevent irreversible planetary change [5].

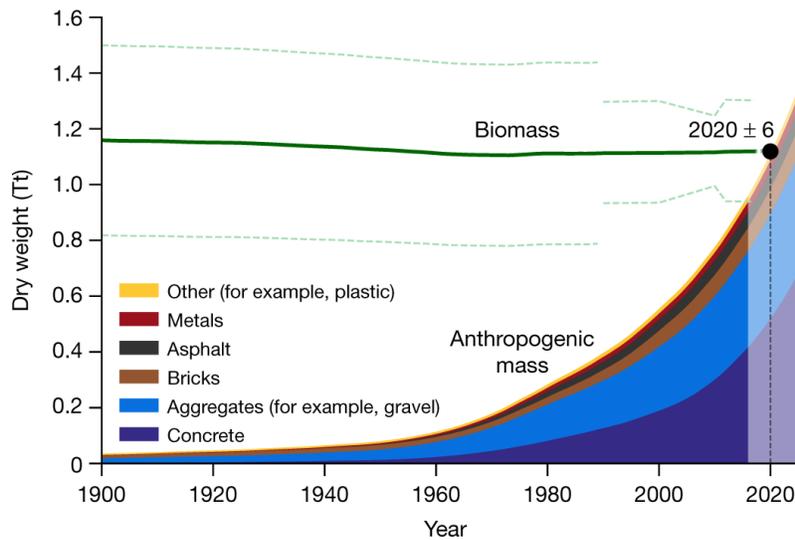


FIGURE 1.1.2 – Global human-made mass exceeds all living biomass.

© Nature. E. Elhacham, L. Ben-Uri, J. Grozovski, et al. 2020 p442

It is important to recognize that this crisis has been decades in the making. Since the initial debates about climate change in the 70’s with the United Nations Conference on the Human Environment, we have targeted different environmental enemies along our studies, from chlorofluorocarbons and ozone depletion to acid rain, deforestation, nuclear proliferation, and now carbon emissions and systemic ecological collapse [1]. And yet, we insist on ignoring the restrictions that scientists defend by treating them as gentle suggestions. We continue the dynamic of “business as usual” even if now burning fossil fuels is obstructing our capacity to keep burning fuels, we keep going, just green-labeling the usual dynamics with a little concerned look over our shoulders. We need a drastic mobilization on a historical scale, yet we are too afraid to recognize the severity of the situation, as it will completely change the foundations of our world [4]. These are not isolated threats; they are layered and interconnected, as the United Nations Development Programme notes, “they are stacked on top of each other, interacting and amplifying in unpredictable ways” [1].

The concept of the Anthropocene has emerged to capture this condition, describing an era in which human activity has become a dominant force shaping planetary systems, from climate to biodiversity. It acknowledges that human influence now shapes everything from atmospheric chemistry to species distribution and geophysical patterns. The uncertainties of the Anthropocene are already affecting human health, not only through direct environmental impacts but through their psychological and social consequences. Increasing levels of trauma, climate anxiety, food insecurity, and public health crises signal a deep mental and emotional toll, especially among the youngest and most marginalized communities. Crucially, it also reframes the risk, “For the first time in human history, anthropogenic existential threats loom larger than those from natural hazards” [1]

B. Paradigm

The previous section addressed some of the most severe structural forces and hard data shaping our time. Yet these situations also have a profound impact on the paradigmatic and philosophical frameworks through which we interpret the present. These new paradigms remain under debate and continue to emerge contingently, day by day. Any attempt to address them here is necessary in a provisional manner, as there is no final word yet on how humanity is repositioning itself in the face of these increasingly urgent global conditions.

After careful research on the subject, we can distinguish the various studies by the United Nations Development Programme (UNDP) that highlight key obstacles to healthy human development, understood not merely as material well-being, but also as the capacity to feel that one has genuine opportunities in life. Such a vision directly clashes with the dominant paradigms that tend to privilege market efficiency, control, and the acceleration of technology over social dimensions [1].

The COVID-19 pandemic brought a profound systemic shift, evidencing the intricate connections linking diverse planetary axes, from public health to economic resilience. It also revealed the disruptive force of such events, which, as we advance through the Anthropocene, are likely to become increasingly frequent and severe. Pandemics, alongside armed conflicts, the cost-of-living crisis, and accelerating ecological disasters, have indisputably reshaped our perception of the world and our place in it, characterized by a rising sense of **uncertainty** as humanity has never experienced [1].

While uncertainty has always been part of the human condition, the current model of uncertainty belongs to a new category, driven by human action, layering and intertwining in a complexity that far exceeds the capacity of our socio-ecological systems. Rather than seeking to return to a past sense of control, efforts should be directed toward investing in human development that fosters creativity and collective cooperation to face these new challenges [1].

According to the 2021-2022 Human Development Report, three main currents of uncertainty can be distinguished:

- The dangerous planetary shifts of the Anthropocene.
- The search for deep social transformations on a scale comparable to those that followed the Industrial Revolution.
- The intensifying polarization of societies, amplified by emerging digital technologies such as social media and artificial intelligence ^[1].

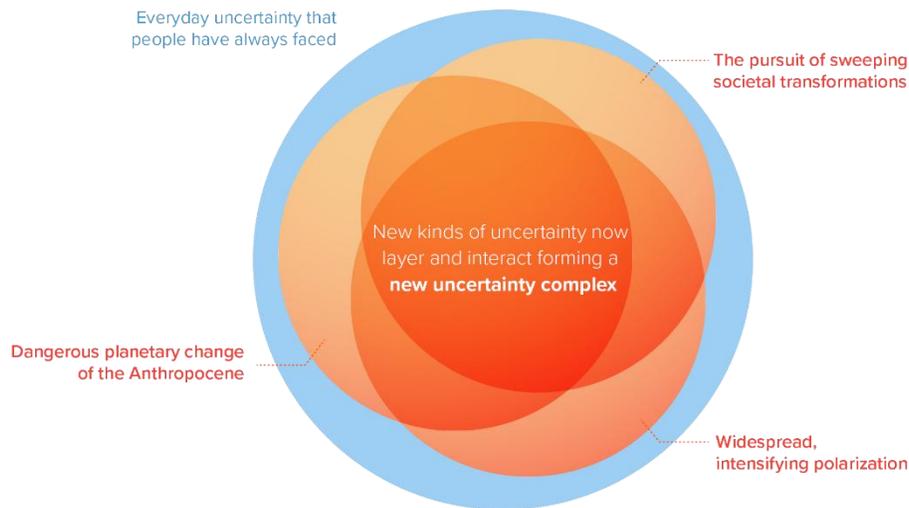


FIGURE 1.1.3 – A new uncertainty complex, UNDP.2022 ^{[1]p3}

In this landscape of constant change, **inequality** has also become a central factor shaping the contemporary paradigm. The stark disparity of opportunities, both within and between countries, fuels a growing sense of general instability, especially as billions face rising living costs, food insecurity, and deepening political divisions. Under such conditions, extremism and demagoguery flourish, amplified by technologies that magnify polarization and large-scale disinformation ^[1].

This leads us to one of the most striking paradoxes of the Anthropocene, now that humanity has gained an unprecedented power to influence the planet's trajectory, this does not necessarily mean we have gained more control over what will happen ^[6]. This inconsistency forces us to rethink ideas that have been deeply rooted since the Enlightenment, such as the rigid separation between **nature and society**. Thinkers such as Philippe Descola argue for moving beyond such Cartesian distinctions to grasp the complex entanglements that characterize our present ^[7].

A post-Cartesian narrative challenges the tendency to attribute the environmental crisis to the “natural” characteristics of our species, as if our planetary impact were biologically unavoidable. Instead, reframing the relationship between the natural and social sciences as interdependent enables us to integrate social theory with climatology, geology, and ecology to address global crises more effectively. Bringing social and political systems into the discussion makes it clear that property regimes, power structures, and ideological frameworks that drive the planet’s trajectory are not immutable natural laws. This broader opening invites the postmodern human to look beyond the capitalist assumption that market value is as fixed and unquestionable as the laws of physics ^[6].

C. Technocene

We have discussed some of the most important fundamental forces shaping our era, along with their repercussions on the narratives through which humans position themselves in the world. Yet there is at least one additional force whose exponential growth over the past century has increased its relevance. The exponential expansion of technological systems has become one of the defining conditions of contemporary society. The role it plays and its consequences, however, are not always clear. The following is a synthesis of some of the most relevant discussions on the topic in recent years.

Today, technology is everywhere, in our phones we carry with us all day, our cars, and even many of our household devices, from thermostats to vacuum cleaners, are now “smart.” Increasingly, our lives serve to feed and, in turn, be shaped by algorithms, most often driven by artificial intelligence. This pervasive presence is not necessarily negative in itself, after all, technologies are human creations as ethically neutral as any other tool. Under this lens, technology reframes itself as far more paradoxical than a magic wand capable of solving all problems, it both warms the planet with its usage and promises a cleaner future through innovations such as nuclear fusion ^[1].

Paradoxically, in this age of unprecedented communication, a growing problem of isolation emerges, the more online interactions replace offline ones, the more political participation, critical thinking, and other forms of cultural engagement tend to diminish. Digital addiction is one of the most pressing and still poorly understood challenges. Dopamine and adrenaline rushes triggered by the random-reward mechanics of social media that “hacked” our brain’s reward centers, producing vast amounts of data that further refine their system, while burying ever-expanding servers under an unlimited energy and environmental cost ^[1].

Unlike other primates with whom we are closely related, human social relations can be tied to objects external to the body. Technology plays a central role in shaping social persuasion, yet it is always mediated by individual or collective perception and is traditionally

understood as independent from human consciousness. Researchers like Alf Hornborg propose three categories to better understand the role of technology in human societies. The first, “*non-globalised technology*” includes artifacts that require neither human perception nor market exchange to function, such as a key, whose utility is independent of how it is perceived or valued. The second category, “*local magic*” refers to artifacts that operate purely based on human perception, such as coins. Finally, “*globalised technology*” is the most complex, functions independently of perception at a technical level, but globally depends on market value and human intention, for example, the internet, which has a fixed technical capacity but acquires a second, collective value through shared interpretation. These objects, including technologies, so deeply entangle human relationships that determining the boundaries between materiality, sociability, and imagination has never been more uncertain. Three centuries of harnessing technological development as the spearhead of global imperial expansion have left a deeply entrenched, fetishized conception that now stumbles upon the new global challenges ^[6].

From the Industrial Revolution to the present day, technologies have been distributed in a highly uneven way, the affluence of a highly technological modernity is far from universal. On the contrary, it relies on stark disparities in the purchasing power of individuals and nations to function as a status symbol, functioning is a mechanism of unequal exchange. The sociocultural relationships of technological development are so complex and intertwined that it is impossible to imagine a technological landscape independent of resource flows. Likewise, mainstream economics tend to keep this unequal exchange out of public awareness, sustaining the narrative of “technological progress” as a panacea for labor and environmental burdens, an idea fetishized and particularly internalized by those with lower purchasing power. The uneven accumulation of technological mass, visible in nighttime satellite images, reveals a stark truth, the places with the greatest capacity to accumulate fossil fuels are also those best equipped to dissipate their consequences ^[6].

The transitions required to confront the Anthropocene, according to some, are comparable in scale to the leap from agrarian to industrial societies. They present immense challenges even in the best-case scenarios, especially when set against tides of inequality and social fragmentation that could easily lead to outcomes contrary to those intended ^[1]. These risks nonetheless demand careful planning to ensure the integration of new clean technologies into a fair market, including reevaluating the environmental and social risks of resource extraction for technologies such as solar panels and wind turbines. Addressing these anthropogenic transformations of the biosphere requires recognizing the interconnected role of technologies alongside the rest of the planet’s structural forces. In this light, some scholars have begun to propose an additional framework for understanding these phenomena, the “*Technocene*” that vindicates the fundamental role that technologies play and will continue to play in this chapter of human history ^[6].

1.2 Design Challenges

By this point, we have mapped a clearer picture of the critical challenges defining our era. Pretending to solve any of them would be far too naïve; however, design disciplines have an intrinsic potential due to their creative nature that puts them in a unique position to work as effective catalysts of change, offering fresh vision and valuable insights that can guide a healthier path for human progress.

We have, as we have seen, received a highly fractured world that has been continuously shaped by deeply intertwined climatic, social, and economic disruptions, alongside shifting narratives that have pushed us away from our static conception of what “natural” means. We have assumed our role as part of this “nature” that shifts planetary trajectories and suffers all its consequences, interiorizing the full range of human dimensions inside this nature. Yet environmental degradation keeps its rhythm as the canonical evolution of technological and cultural advancements ^[8]. As the planet’s health and the life on it deteriorate, we are left with much more than a bad climate, a complicated crisis difficult to grasp in the middle of the storm ^[9].

Moving forward post-Cartesian dualisms opens the possibilities for a new world-ecology facing new ontological politics that seek a more equitable distribution of wealth, where equity and sustainability are central to our vision of the future. Fortunately, these visions appeared when the capitalist model is showing signs of exhaustion and presents the opportunity to reframe the “four cheaps” food, energy, raw materials, and human life. Showing these capitalism contradictions are one of the modernity’s accomplishments, as capitalism internalizes the costs of climate change, new ideas win the opportunity to rise ^[9].

As we go on, **creativity** plays a central role in reimagining our futures where human development can guarantee individual freedoms. To craft new narratives that direct attention and resources to the right actors, **innovation** will also be essential for responding to the upcoming challenges facing humanity. Energy systems, food production, and transportation are just a few of the planetary systems that need more urgently a reformation that blended design approaches can contribute to. A new green economy could transform the current community dynamics into more collaborative ways. The huge necessity we face is ironically the best fuel we have to pressure key innovations, today’s uncertainties may root future stability ^[1].

Technology illustrates this paradox well, as we have seen, they generate a huge bill on environmental and social terms, yet it also offers tools with the potential to address climate-related challenges, enhance learning, improve livelihoods, and facilitate global collaboration. It is up to us to drive sustainably to head towards **hope** by breaking through the mental and structural barriers that limit our imagination, and engaging in a deep creative reconstruction that expands what we believe is possible ^[1].

Design has the capacity to rethink the boundaries, whether conceptual, cultural, or infrastructural, by offering tools to reinterpret constraints and create new solutions for a changing world. Recent trends toward integrating nature-based solutions into human development offer a unique opportunity to enhance natural resources while protecting people from shocks, promoting economic and food security, and expanding the choices available to them ^[1].

This sort of approach with multi-faced impacts must be an example to follow, excelling innovation that involves many realms, and not just technological but also socially, focusing on emergent bottom-up participatory processes that analyse every phenomenon within its individual metrics and contexts. Only widely spread joint efforts can face the continuously extending pessimism that characterizes the times we live in, where our most important recourse is building a shared narrative that bridges people together and unlocks human potential by tapping into creativity and channeling our diversity towards thriving futures ^[1].

Defining the design path in this context requires precision. It must foster creativity and innovation, support human development in all its dimensions, and integrate ecological principles at every stage. Among the many possible approaches, none aligns more fully with these conditions than environmental design, an orientation that addresses global crises by embedding sustainability, collaboration, and regeneration at the heart of the design process.

Architecture, in this sense, cannot continue operating under outdated paradigms. Facing the intertwined crises of our time demands a shift toward holistic, cross-disciplinary collaboration, in which architects work alongside scientists, engineers, social innovators, and local communities to address the complex, interconnected challenges of our generation.

1.3 Research Questions

With a clearer reading of today's global crises and the role of design within them, we can now move forward in a more precise direction. Yet the path toward sustainable architecture remains filled with uncertainties that must be addressed before building a solid foundation. These uncertainties converge around three central research questions.

What is sustainable architecture? - This apparently simple question has proven surprisingly complex to answer. Part of the challenge lies in the fact that sustainable architecture is deeply entangled with a wide range of related fields, such as environmental design or green building, each with its own definitions, tools, and priorities. Over the decades, the field has fragmented into specialized niches, each claiming authority over certain aspects of sustainability, energy efficiency, carbon footprint, indoor comfort, or life cycle performance. While these contributions are valuable, this fragmentation often produces a narrow and partial view. To define sustainable architecture in a meaningful way, we must trace the historical evolution of these overlapping visions and articulate a framework broad enough to encompass them, yet precise enough to serve as a common ground.

How can we evaluate it? - Once we attempt a working definition of sustainable architecture, the next challenge is evaluation. How can we determine whether a project truly meets the standards of sustainability, or whether one project can be considered “more sustainable” than another? Existing frameworks, such as LEED, BREEAM, or LCA methodologies, have provided measurable criteria that allow for comparison. The risk is a reductionist view where sustainability is equated with compliance checklists or used as a marketing label. Thus, a critical task is to explore not only the strengths but also the weaknesses of these evaluation systems, and to question whether sustainability can ever be fully captured through metrics alone. This requires developing a broader lens that acknowledges complexity, embraces qualitative aspects, and recognizes the diverse realms of sustainability.

How do the dimensions of sustainable projects interrelate? - Finally, even if we establish what sustainable architecture is and the realms through which it can be evaluated, a further layer of complexity emerges. These dimensions of sustainability do not operate in isolation, on the contrary, they constantly influence and reshape one another. Understanding these interrelations is essential to move beyond static approaches and toward a systemic vision of sustainability. Technology plays a pivotal role in this process, as contemporary design practice is mostly structured around toolchains that guide decision-making across the project's development. Therefore, evaluating sustainability today requires looking not only at each dimension independently, but also at how toolchains interrelate and condition the outcomes of design. True innovation does not lie in technology alone, but in integrating these technological processes within a framework that converges broader visions and optimizes the efficient integration of complex processes for pragmatic outcomes.

Chapter 2

Sustainable Architecture Views

*“One of the first conditions of happiness is that the link
between man and nature shall not be broken.”*

-Lev Tolstoi

2.1 Evolution of Environmental Thinking

Narrowing down the problem to the field of sustainable architecture appears promising so far, but defining what falls under the umbrella of sustainable architecture is far from straightforward. The term itself is linked to multiple disciplines, inevitably exposing a semantic gap when words like “sustainable,” “ecological,” or “environmental” are often used interchangeably. In this section, drawing from key bibliographic sources, we will propose a possible organization chart that situates the diverse and sometimes conflicting definitions at play.

As a disclosure for the following section, it is important to remember that everything presented is a limited interpretation of years of history and as many visions as characters involved. Our effort lies in providing a clear and practical overview to visualize the streams of knowledge, beyond neglecting the depth of any individual field. Yet the very attempt to enclose knowledge within a fixed system that accurately portrays its interrelations is inevitably evasive, susceptible to errors, bias, and political frameworks. Organizing information is in itself a political act that perpetuates narratives and power structures, for this reason, giving place for new knowledge structures becomes so important.^[8]

It was challenging to identify an appropriate entry point into the topic, since many of these concepts appear to be floating in parallel, with some receiving considerably more attention in publications and academic debate. Nevertheless, the historical timeline proved to be a valuable anchor, offering a sense of linearity that helps us organize the discussion with greater clarity. However, this approach also risks conveying an overly simplistic impression of causality, as if developments followed a neat sequence from beginning to end. Many of these histories unfolded simultaneously, often branching in multiple directions rather than converging into a single, linear narrative.

Defining a precise starting point for sustainability-related design is nearly impossible, as it lies somehow at the very core of architecture itself; the act of adapting to the challenges of their environment to ensure comfort and survival. This impulse is as ancient as any other inherent human trait, and not even exclusive to humans. Archeological records show some of the earliest manufactured shelters built from mammoth skulls and bones by societies with an extremely limited amount of energy available for anything that was not related to survival. A decisive shift occurred with the domestication of today's cereal ancestors, which created a significant surplus of energy that was available to spend on more longstanding buildings. Beginning around 12,000 years ago, this process, commonly referred to as the *Neolithic Revolution*, marked a profound paradigm shift in how shelters were conceived. With more resources available, ancient settlements such as those in Turkey or the Dogon cliff dwellings in Mali began to accumulate intergenerational knowledge, refining construction techniques and adapting them to optimize their specific energy contexts ^[10].



FIGURE 2.1.1 – Building B of Göbekli Tepe, Turkey.
Photograph © DAI, Göbekli Tepe Project. UNESCO World Heritage Centre

During this period, the available evidence is quite fragmented, yet it is clear that a gradual process started occurring as populations grew, societies became more complex, eventually leading to the rise of civilizations in a new period called the *Urban Revolution*. This transition occurred at different times across regions and, with it, unleashed a new architectural paradigm driven by an increasing surplus of energy and knowledge that could now be invested in more monumental and standardized forms of construction. In these early cities, such as Uruk in present-day Iraq, we see the early deployment of complex building practices, rooted in the specialization enabled by larger populations no longer entirely devoted to food production ^[10]. These advances accumulated in generational knowledge that fostered the standardization of processes and the refinement of adaptation strategies that could optimize further use of local materials, proper solar orientation, and the cooling effects of wind and water, conditions that, although they were not intentionally “sustainable” by today’s definition, inherently reflected a close alignment with local resources and environmental limits. Moreover, it is also worth to note that this period also produced the first written document on architectural theory Vitruvius’s *De Architectura* by the year 15 BCE, which established enduring precedents of environmental adaptation and user comfort, including solar access principles, and the importance of adapting buildings to the diversities of climate, these comprehend a milestone for Roman civilization and many generations to come ^[11].

With the fall of the Western Roman Empire, much of Europe entered a period of profound economic and energetic contraction. A contraction that followed metabolic principles since most cities shrank or disappeared without the agricultural systems and infrastructure that had sustained the imperial surplus, the reduction of available sources, food to sustain labor, and wood to provide heat and cooking fuel, drastically limited the production capacity. Compelled to salvage bricks and stone from Roman ruins, reusing them as meaningful construction materials, centuries of architectural skill regressed, the specialists vanished, and communities turned to vernacular construction*, relying on local resources and generational knowledge to adapt to their environments, but without the systematic theoretical frameworks that had characterized classical traditions ^[10].

Outside of Europe, however, architectural traditions followed different trajectories. In the Middle East, monumental buildings continued to flourish, and sophisticated climatic strategies were refined, including the control of daylight, air circulation, humidity, and ambient temperature through elements such as courtyards and wind towers. Across Asia, population growth fostered architectural sophistication as well, with dynasties such as the Song in China channeling surplus resources into urban development and advanced building techniques. In the Americas, ancient civilizations developed their own environmental strategies, embedding solar geometry and orientation principles into the layout of cities and ceremonial structures. These developments reveal that while Europe experienced regression, other regions maintained continuity in architectural experimentation, preserving systemic understandings of climate and material efficiency ^{[10][11]}.

* vernacular construction; building practices based on local materials, climate, and traditions, typically developed without formal architectural theory.



FIGURE 2.1.2 – Wind Towers in Historic City of Yazd, Iran.

Photograph © ICHHTO, Mohammad Hosseini. UNESCO World Heritage Centre

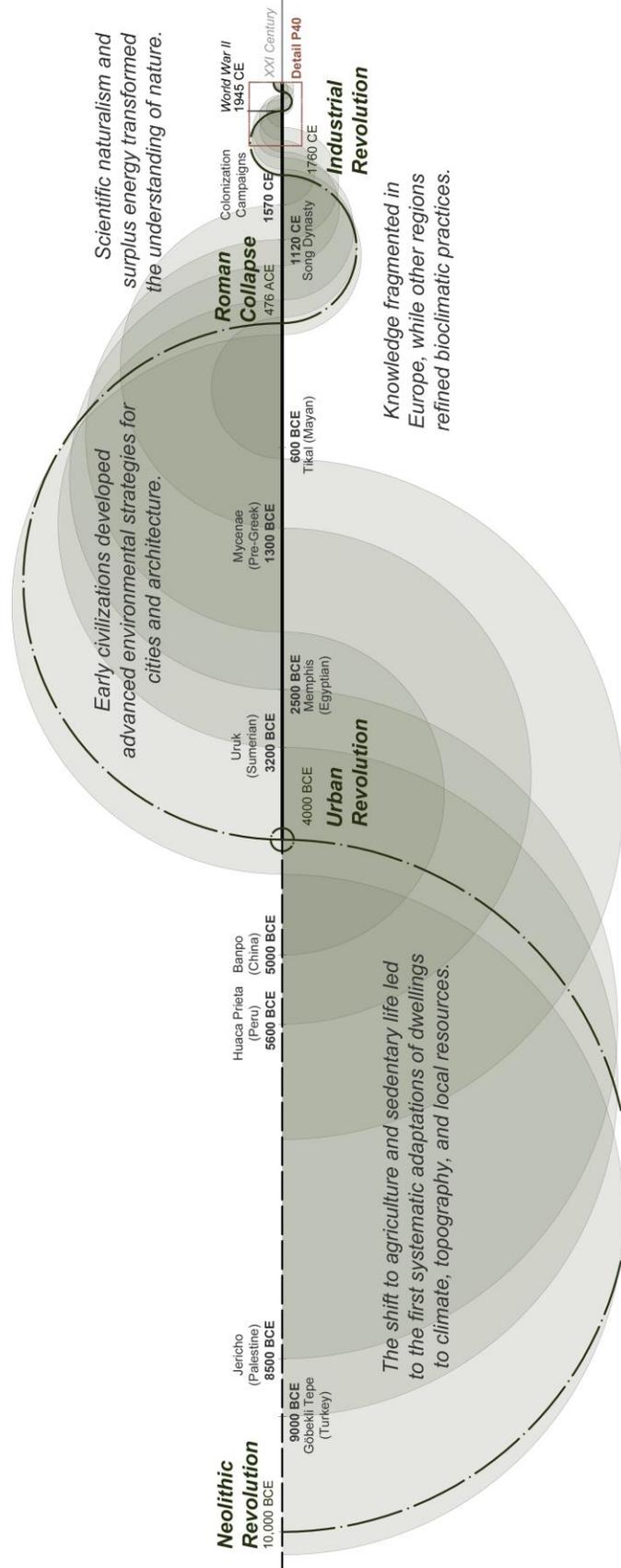
By the late Middle Ages, Europe gradually rebuilt most of the knowledge lost, through both the re-exploration of Roman findings and the cultural revival of the Renaissance ^[10]. Colonization then confronted Europeans with climates radically different from their own, demanding systematic manuals for settlement planning overseas that consider more complex studies of solar geometry for city layouts, as well as passive design strategies such as orientation for ventilation, shadings, and courtyard typologies integrated into building practices. This effort marked the first large-scale attempts at acclimatization and geoengineering*. By 1573 CE, the Spanish city design was codified by the document *The Laws of the Indies*, which mandated a standardized grid plan based on orientations, together with the British idea of climate being directly linked to health, culture, and moral hygiene in the interest of making colonies more “salubrious” for settlers. As Richard Grove argues in *Green Imperialism*, these discourses often masked the economic imperative of exploiting land and resources ^[8].

As the early industrial era unfolded, architecture was overwhelmed by an unprecedented energy surplus that reshaped both material and intellectual practices. Lydia Kallipoliti identifies this era with the paradigm of “**Naturalism**”, when emerging sciences reframed humanity’s place within nature. These bio-philosophical thoughts were propelled by significant accomplishments in natural sciences, such as Darwin’s *Origin of Species*, that broke with the idea of nature as wilderness separated from man, while Ernst Haeckel’s work also coined the term “ecology”, from Greek *oikos* or “place of dwelling”, to study the relations between organisms and their environments ^[8]. Meanwhile, Britain’s abundant coal reserves transformed energy economies from wood to coal, and industries such as glass and brick were revolutionized, rising performance thresholds in rubrics such as daylight, thermal mass, and public health. This urban growth was fueled by cheap energy, improved crops introduced from the Americas, and abundant labor ^[10]. These parallel trajectories set the foundations for a new design of spaces that could be integrated with natural forces ^[8].

* geoengineering; deliberate large-scale modification of the Earth’s environmental systems | 19
such as climate, land, or water.

DIAGRAM 2.A – General timeline of Sustainable Architecture Paradigms.

The following timeline outlines the main paradigm shifts in environmental thinking, highlighting the coexistence of parallel developments across different geographic and cultural contexts rather than following a single linear narrative.



The framework draws on key concepts from Barnabas Calder [10] and Lydia Kallipoliti [8], highlighting how diverse contexts shaped the evolution of architectural responses to the environment.

*Years based to complete this chart were simplified from the actual timespan that most settlements were developed and inhabited. For further information of archeological sites please refer to UNESCO World Heritage Convention Official Website <https://whc.unesco.org/en>

2.2 Modern Disciplines

As modernity approaches, we begin to recognize a paradigm shift closer to contemporary studies. By the end of the 19th century, natural sciences had unfolded into a wide range of disciplines, and scientific thought had begun to permeate architectural practice. In this context, pioneers such as Ellen Swallow Richards reinterpreted the notion of ecology in household terms, considering homes the central focus for improving societal health and, by extension, well-being. With a special focus on sanitation, water management, nutrition, and efficient home design, she coined the approach “*house economics*” sewing an early vision of sustainability that linked humanistic improvement with the environment ^[8].

Architects of the modern movement also introduced their own interpretations of environmental science's views; Le Corbusier's famous “machine for living” portrayed the idea of a performative dwelling, with a particular concern for light, color, and orientation as seen in his “Unite d'Habitation” in Marseille (1952), though many of these ambitions yielded contradictory results in practice. Alvar Aalto, by contrast, emphasized the psychophysical dimensions of architecture and expressed concern for biological systems as a principle for architecture. Across projects such as the Sanatorium of Paimio (1933), the Seniors' Dormitory (1948), and Säynätsalo City Hall (1952), Aalto combined technical functionality with comfort, natural light, and heliotropic layouts that anticipated later bioclimatic passive strategies*. Walter Gropius, meanwhile, explored urban form through solar and sky access criteria in planning social housing, as exemplified in the Dessau-Törten Siedlung in Germany (1926). Although it remains unclear how deeply these figures engaged with environmental phenomena, or how much they simply chose to overlook, certain features of their work nonetheless suggest an emerging environmental consciousness, even if it was not articulated at the time ^[11].

Among the modern masters, it is worth noting Frank Lloyd Wright, whose vision marked one of the first architectural trends to consciously advocate for a harmonic dialogue between architecture and the natural world. Emerging in the early 1930s, his concept of **Organic Architecture** introduced a modern vision that sought to integrate human development within its environment, grounding buildings in their landscapes through formal composition, material choice, and spatial narrative. This “*immersionist*” approach, however, was more than an aesthetic, it was also a worldview, a democratic ideal in which nature offered both inspiration and moral guidance ^[8]. His early works, such as the Frederick Robie House (1910), already displayed environmental awareness, with shaded courts, terraced overhangs, and solar-oriented windows that created naturally cool interiors. Later projects, like the “Solar Hemicycle,” explicitly explored the optimization of solar energy through form and layout, anticipating environmental design principles before they had a formal name. Wright's proposals, from intimate dwellings to visionary plans like “Broadacre City”, reveal both his immersionist belief in nature as a guiding force and his enduring ambition to harmonize modern life with its surroundings ^{[8][11]}.

* *passive strategies; architectural techniques that regulate indoor comfort through natural means such as orientation, ventilation, shading, and thermal mass.* | 21



FIGURE 2.2.1 – Solar Hemicycle House, Frank Lloyd Wright.
Photograph © Jeff Dean. Wisconsin Historical Society. 1944

After the scarcity inherited from World War II, awareness grew of the finitude of natural resources, and the rising consequences of industrial modernity pushed architecture to shift its focus from the visual and moral harmony of previous visions toward a more systematic study pursuing environmental balance. Together with powerful images such as those from the Apollo 8 mission (1968), which presented humanity as sharing a single planet, embracing a desire for unity within the collective conscience. From this context emerged what has been described as “**Synthetic Naturalism**”, understood as an artificial ecology that sought to replicate natural cycles in man-made systems. This development signaled the end of natural sciences as independent fields and consolidated a merged approach that joined ideas of scientific inquiry, cybernetics*, and architectural practice, establishing strong bonds between them. This exchange of languages and tools fostered a paradigm that framed ecological and humanitarian aspects into interrelated systems, comparable to computer circuits, that could be broken down into components and defined in terms of input and output. This reductionist vision shaped the next architectural generation, driven by environmental performance seen in measurable energy flows and viewing buildings as tools for addressing planetary crises, reinforcing a strong positivist standard still evident today^[8].

An early and influential contribution to this line of thinking was *American Building: The Forces That Shape It*, written by the American architect James Marston Fitch in 1948^[12]. In this pioneering work, Fitch sought to trace the forces that had formed American architecture since the 1600s, offering a broad historical classification by eras while identifying key elements such as the building envelope, indoor temperature regulation, air quality and health, lighting, acoustics, climate, solar energy, urban planning, and aesthetics^[12]. Through this comprehensive analysis, Fitch established the conceptual basis for what would later evolve into three major directions of environmental thought for the rest of the century: bioclimatic, environmental, and sustainable design.

* cybernetics; field founded by Norbert Wiener in the 1940s, focused on control and communication in machines.

Fitch's concern with the physical behavior of buildings, their capacity to adapt to climatic conditions, micro-climates, and solar orientation, reveals an early scientific understanding of architecture as an instrument for environmental control, aimed at providing comfort and reducing dependence on mechanical systems, placing him as an important precursor of the bioclimatic design [12]. He also explored the building as a *mediating device* between the body and nature, which he described as a “third environment” in which architecture becomes a spatial interface shaping the relationship between humans and their surroundings. This notion anticipates the later field of environmental design, which would reframe architecture as a study of human spatial experience, perception, and social behavior within designed settings [8]. Furthermore, his acknowledgment of the diverse stakeholders involved in construction, architects, manufacturers, investors, landlords, and users brought a socio-economic dimension to his argument that aligns closely with the urban and systemic thinking of sustainable design [13].

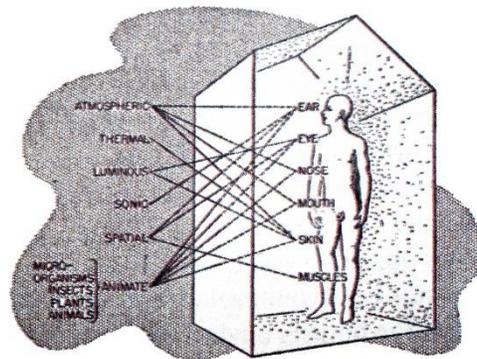


FIGURE 2.2.2 – Third Environment, James Fitch. 1948 [12]p148

Influenced by Fitch's perspective, Victor and Aladar Olgyay expanded some of these ideas through a series of studies that culminated in *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (1963) [14], where the term “**Bioclimatic Design**” was formally introduced, derived from the Greek *bios* (life) and *klima* (climate). This emerging view positioned climate as a fundamental design parameter and man as the principal metric in architecture. Through a biophysical approach grounded in several sciences, such as biology, meteorology, and engineering, it is expected that architecture will synthesize these results and formalize their expression. Seeking to ensure a comfortable microclimate without relying on mechanical systems, it relied on passive strategies that applied physical principles such as solar orientation, cross-ventilation, shading, and thermal mass to adapt buildings to their environments. This interrelationship between form and climate was only possible thanks to the extensive work of climatologists such as Wladimir Köppen and Rudolf Geiger, whose studies on global climate classifications, microclimatic phenomena, and the influence of solar activity, vegetation, and living organisms provided the scientific foundation for these architectural developments [8][11][14].

Moreover, the insightful vision of the user as the efficiency indicator for the building introduced new biological tools that shaped the methodological framework of bioclimatic design. Comfort zones defined by human physiological responses to environmental factors, such as light, sound, temperature, humidity, air movement, and radiation, led to innovative representations such as the psychrometric chart, introduced in *Man, Climate and Architecture* (1969) by Baruch Givoni. The bioclimatic approach was enthusiastically embraced by the architectural guild, prompting further contributions, notably Reyner Banham's *The Architecture of the Well-Tempered Environment* (1969), which critically expanded the understanding of technology and comfort by examining how mechanical systems redefined the interior as a controlled bubble, linking it to medical insights on the health implications of unregulated airflow. Paradoxically, these efforts to create the perfect indoor environment, combined with modernism's fascination with technology, fostered a deep dependency on mechanical systems and extended indoor living, while simultaneously propelling the evolution of technology as a design agent, a trajectory later embodied in the "high-tech" movement, exemplified by the *Centre Pompidou* (1977) in Paris by Renzo Piano, Richard Rogers, and Gianfranco Franchini [8][11].

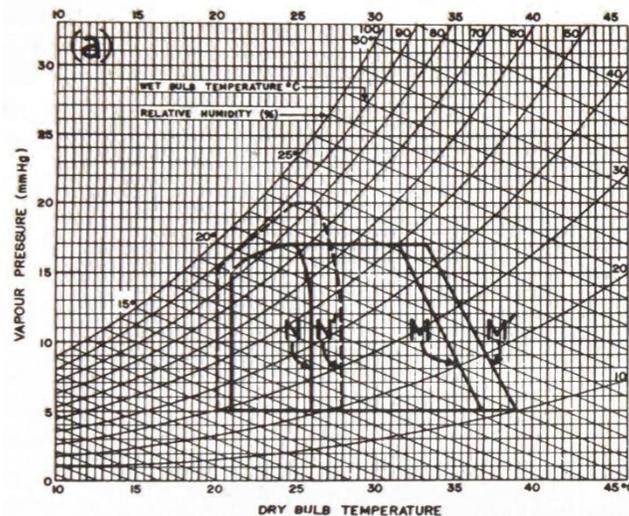


FIGURE 2.2.3 – Psychrometric Chart, Baruch Givoni.
© *Man, Climate and Architecture*. 1969 p.314

Following the growing fascination with environmental studies, the mid-twentieth century proved fertile for the emergence of new design visions. Many of these perspectives were so closely intertwined and overlapping that it becomes difficult to distinguish which ideas belong to which discipline, and in most cases, one will be deeply involved in the others, demonstrating that the wide nomenclature we have created often has many names for the same perspective. Continuing the effort to frame these modern views, we can trace another influential current that developed in parallel to bioclimatic design. Unlike the latter, this new perspective was first used informally within circles of designers, landscape architects, and

planners toward the end of the 1930s. Its earliest formal appearance in the United States is linked to academia, when the Russian émigré Serge Chermayeff, during his years as Design Director at Brooklyn College, employed the term Environmental Design to describe a broader field that integrated modern technology and planning beyond architecture. The concept gained greater visibility when, after joining *Harvard's Graduate School of Design* in the 1950s, Chermayeff was asked to create a cross-departmental course that united architecture, landscape architecture, and planning, which he officially titled “**Environmental Design**”. This initiative later inspired a series of publications throughout the 1960s and 1970s, in which he expanded on community and social studies within the field ^[15].

The term's consolidation arrived in 1959, when William W. Wurster, as dean of *Berkeley's College of Architecture*, founded the new *College of Environmental Design (CED)* by merging the departments of Architecture, Landscape Architecture, and City and Regional Planning, following Harvard's precedent. As with most intellectual transformations, this one was collectively constructed. Scholars such as Christopher Alexander, Kevin Lynch, and Amos Rapoport profoundly shaped its scope. Alexander's “Design by Research” curriculum introduced mathematical models, cognitive science, and artificial intelligence into the design process, later evolving into studies of the pattern language approach grounded in cognitive anthropology. Lynch, renowned for *The Image of the City* (1960), connected visual perception with scientific inquiry, building a new body of knowledge about urban form and its legibility. Rapoport, in turn, drew from anthropology to articulate the relationship between culture, behavior, and the built environment, strengthening the human dimension of environmental design ^[15]. By 1968, the creation of the *Environmental Design Research Association (EDRA)* further expanded this multidisciplinary framework, promoting environments that respond to human and ecological needs ^[16], while organizations such as the *Joint Center for Urban Studies* bridged sociology, economics, and design research, providing a more scientific basis for the field and an important precedent for later sustainability approaches.

The publication of Richard P. Dober's *Environmental Design* in 1969 represented one of the first comprehensive articulations of the discipline. Dober defined environmental design as a responsive tool to confront pollution and environmental degradation while making human habitation enjoyable, stimulating, and healthy. He envisioned it as “*an art larger than architecture, more comprehensive than planning, and more sensitive than engineering,*” placing emphasis on visual order, livability, and a sense of place ^[17]. Unlike the bioclimatic approach, grounded in biological and physical parameters, environmental design expanded its focus toward the social, perceptual, and cultural dimensions of human environments. In the postwar context, driven by demographic growth and urban renewal, its ambition to merge scientific reasoning ^[15] with humanistic values made environmental design a central paradigm in redefining modern architecture and planning.

By the late 60s, empowered by the collective sense of unity inherited from the Apollo 8 mission and permeated by the countercultural ideals of the hippie movement, a strong current of environmental activism spread across the United States and Europe. The decade was marked by a growing disillusionment with the modern industrial order and a rising awareness of the planet's finitude. The publication of *The Limits to Growth* (Club of Rome, 1972) demonstrated the systemic tensions between continuous economic expansion and planetary limits, becoming a manifesto for ecological consciousness and a catalyst for new design ethics ^[13].

Within this atmosphere, the environmental dialogue took on a militant tone, challenging institutional hierarchies, embracing bottom-up practices, and reclaiming design as a form of social and political resistance. From this context emerged the “*autonomist*” and “*outlaw*” movements, which sought to reimagine the human habitat through self-sufficiency and technological independence, as pictured in the *Architectural Design* magazine of 1976 devoted to Autonomous Houses. Experimental communities and designers explored closed-loop systems, renewable energy, and local material reuse as strategies for autonomy from centralized infrastructures, as many of these settlements were established in the southwest of the US following the example of Trinidad, Colorado, in 1965. Some approached this vision through alternative lifestyles beyond the city, while others expressed it through provocative urban interventions that criticized consumerist waste and the logic of disposability. Iconic examples include the *Heineken WOBO brick* (1963), an early industrial attempt to fuse packaging with building materiality; *Martin Pawley's Garbage Housing* (1975), which reframed waste as a construction resource; and Michael Reynolds' *projects* from 1972 onward, built with discarded cans, glass bottles, and tires to demonstrate a radical model of self-sustaining architecture ^[8]. These initiatives, positioned at the intersection of ecological ethics and social critique, forged a new architectural frontier, one that no longer relied on pristine materials or centralized systems but celebrated the creative reuse of matter and the empowerment of users as agents of change.

These agitated decades gave rise to the first global debates, which, in 1972 in Stockholm, led the United Nations to reach a consensus on atmospheric pollution and its consequences for climate change. Almost a century earlier, in 1896, the chemist Svante Arrhenius started to announce these concerns. Together with the general environmental degradation and its consequences for humans and non-humans, as Rachel Carson stated in *Silent Spring* a decade earlier in 1962. This started a series of international institutions and summits that ultimately laid the groundwork for the broader conceptualization of sustainability that emerged during the 1980s. The *Brundtland Report* (1987) by the United Nations introduced the now-classic definition of sustainable development as that which “*meets the needs of the present without compromising the ability of future generations to meet their own needs*” ^[18].

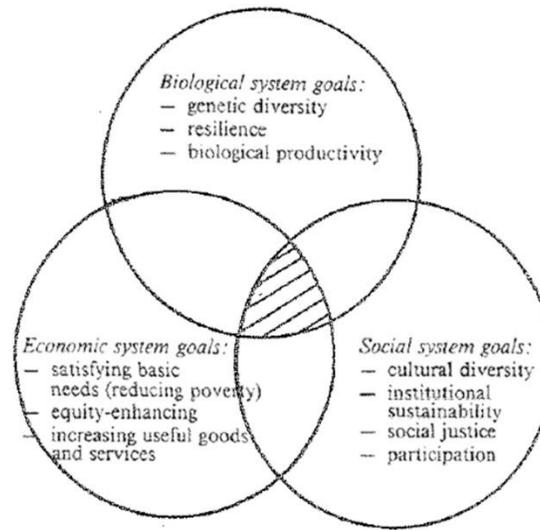


FIGURE 2.2.4 – Sustainable Development, Eduard B. Barbier.
© Foundation for Environmental Conservation 1987. P.104

From this foundation, architecture began to reframe its purpose, translating these evolving views into a new approach labeled **“Sustainable Design”**, conceived as a mediator between environmental responsibility, social well-being, and economic feasibility. Early thinkers, such as Ralph Knowles in *Ecological Planning* (1974), had already anticipated this shift by advocating energy-conscious urban growth and community diversity as natural forms of adaptation ^[11]. By the 1990s, sustainability matured from an activist ideal into a structured design paradigm, promoting measurable environmental performance alongside cultural and ethical awareness. With the strong impulse of the *International Union of Architects (UIA)* and the *American Institute of Architects (AIA)*, which in 1994 published *The Guide to Sustainable Design*, the field consolidated its theoretical and practical framework.

Since then, numerous voices have broadened the notion of sustainability into a holistic vision that reconsiders architecture’s role within planetary systems. It has moved beyond the pursuit of technological efficiency to question the cultural and ethical values underpinning our relationship with nature. True sustainability implies not only minimizing environmental harm but transforming the way architecture engages with ecological, social, and economic dynamics. In this sense, it stands as a renewed understanding of design grounded in ethical awareness, contextual sensitivity, and systemic thinking. Sustainable architecture thus inherits many precedents and future views, merging them within a contemporary framework that values inclusivity, contextual sensitivity, and acts with the beauty of responsibility. This broader approach advocates for design decisions informed by ethical positions as well as a coherent grasp of the interrelated objectives, processes, and systems that define sustainable practice today ^[19].

With the compilation of knowledge gathered throughout the century, multiple design visions developed in parallel, yet another one that seemed to move in the shadows of the others finally gained definition toward the end of the century. Since the foundation of ecology in 1866, many environmental approaches referenced its principles, though few delved fully into the biological dynamics of natural systems. A notable exception was Ian McHarg, whose *Design with Nature* (1969) [20] can be read as a powerful manifesto that renewed the dialogue between territories and their inhabitants. By bringing ecological science together with moral and aesthetic reflection, McHarg called for a cooperative relationship between human and natural processes. Through mapping ecological layers and visualizing their interdependence, he redefined design as a mediator of natural and cultural forces, establishing methodological grounds that anticipated later technologies such as GIS. For McHarg, man was not apart from nature but a participant within it, bound to the biological, social, and spiritual balance of the environment [20].

It was not until 1996, however, that the term “**Ecological Design**” was formally articulated in the homonymous book by Sim Van der Ryn and Stuart Cowan. They defined it as a form of design that integrates with environmental cycles to reduce its impacts, thereby extending McHarg’s ecological ethics into a systemic, multidisciplinary framework. Like environmental design, it sought to preserve the planet’s limited resources, yet it distinguished itself by advocating for a deeper synchronization of human activity with natural cycles. In doing so, ecological design synthesized the dispersed debates of the century into a renewed focus grounded in the natural sciences, ethical cooperation, emotional intelligence, and the inclusion of non-human actors as co-creators in the shaping of our environments [8].

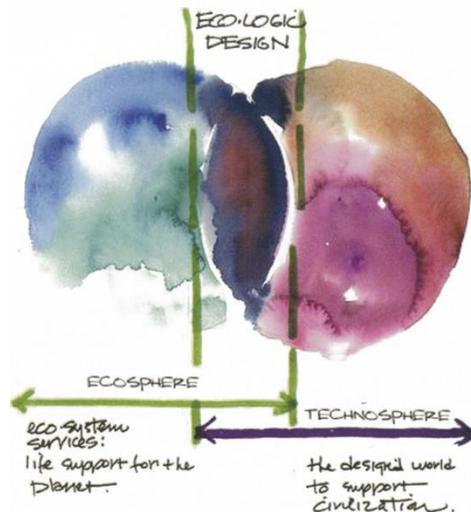
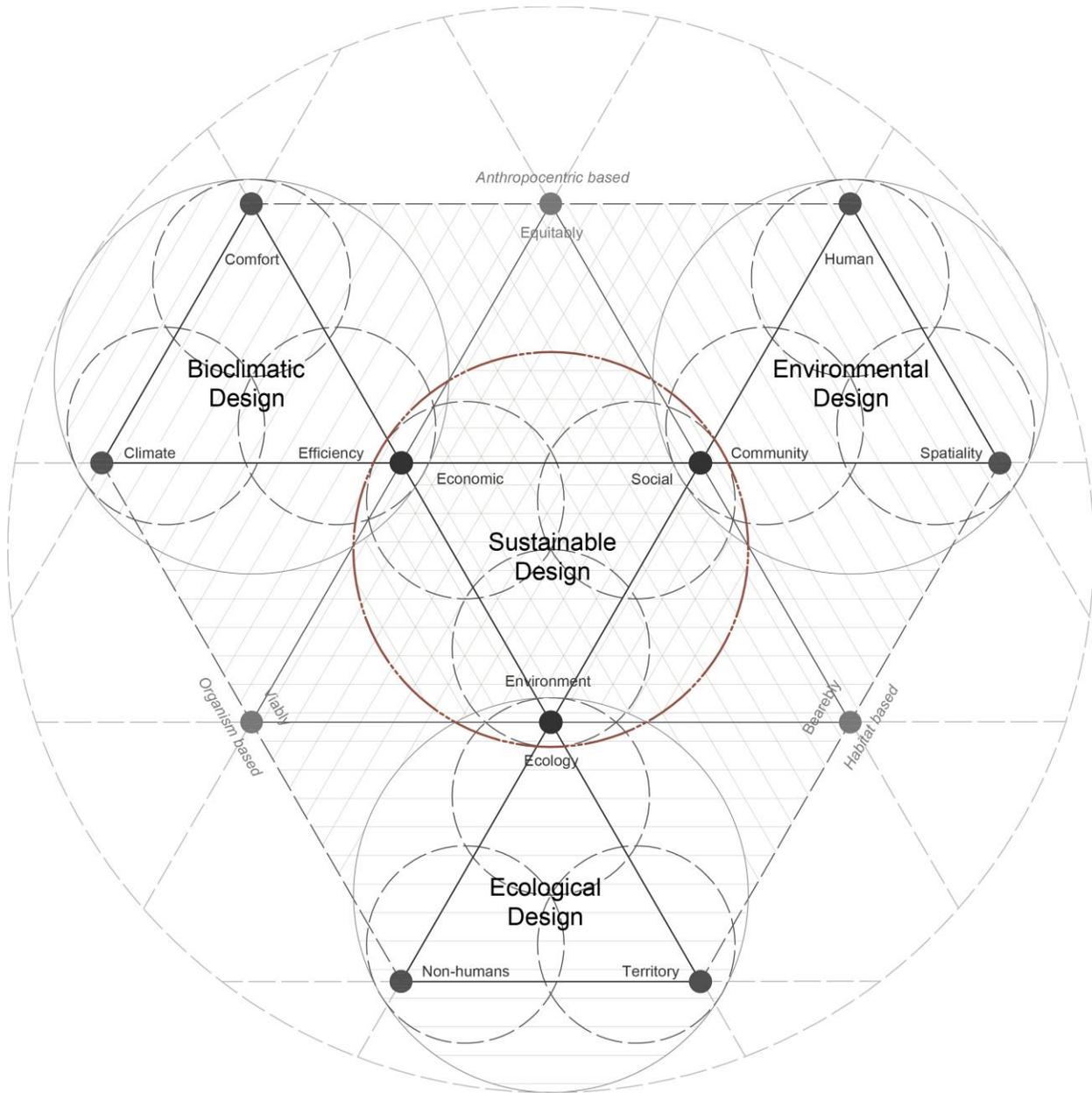


FIGURE 2.2.5 – Eco-Logic Design, Spheres Intersection.
 © Sim van der Ryn, from *Design for Life* 2005.

DIAGRAM 2.B – Venn Diagram of Sustainable Design Related Disciplines.

Building on the diverse perspectives that emerged throughout modernity, this systemic diagram delineates the author’s interpretation of the main characteristics and their interrelations associated with the most representative disciplines.



The aim is to reveal how these overlapping approaches collectively shape a broader environmental discourse, moving beyond categorical labels to emphasize their complementary roles and the integrative quality of their combined vision.

2.3 Ongoing Visions

It might be more than a coincidence that the turn of the century coincided with the growing awareness of unstoppable global crises, soon reframed under the term *Anthropocene*, popularized by Nobel Laureate Paul J. Crutzen and Eugene F. Stoermer under their essay published in 2000. As discussed earlier in the first chapter, humanity was redefined as a geological force inevitably inscribed within nature and no longer external to it. From the existential threat brought by this new condition emerged what Lydia Kallipoliti described as “**Dark Naturalism**”, an era in which humans and non-humans can no longer be separated, and where traditional certainties are progressively dissolved into a dense network of intertwined relationships. This paradigm compels us to rethink a new form of humanism based on non-linear and non-hierarchical relations and one with more humble ways of coexistence with nature. We were forced to abandon the simplistic modern idea of design as a rehabilitative tool, a means of returning to an idealized planetary balance. We now live in a darker condition, where imagination must turn toward what is real and achievable rather than to the fantasy of restoring a lost world, we might rethink how to inhabit its ruins ^[8].

Within this transformation, the rise of a data-driven culture has profoundly altered how we perceive and interpret the world. The previous idea of a closed and understandable system has vanished into a scattered and layered cloud of information that resists total comprehension. This condition forces us to focus on what can be grasped, the small fragments and fragile connections that form part of a much larger, elusive whole. Various terms, such as Capitalocene, Plasticene, or Technocene, have been proposed to describe this moment, each highlighting a different aspect of our reality, yet all trying to frame an age that surpasses human cognition and control. We now coexist with the remnants of industrial and neoliberal systems, surrounded by artificial natures, such as the plastic islands of the Pacific that have become part of the planetary fabric itself. Technology, once a symbol of progress, has turned into both our menace and our defense, functioning as an indispensable extension of the human body. In this still-unfolding era, we are called to acknowledge the contradictory vision of what cannot be cognised by human minds and to assume responsibility in redefining our role, not as external observers of nature, but as participants within an entangled and uncertain reality that demands new forms of adaptation and awareness ^{[6] [8]}.

As one of the architectural visions that emerged during the transition of the past century and built upon the systemic view of sustainability developed by previous generations. It dates back to the early 1990s, when the UK’s *Building Research Establishment* introduced the *Building Research Establishment Environmental Assessment Method (BREEAM)*, the first environmental assessment tool to define a comprehensive framework for evaluating the performance of new and existing buildings. As the first to use the term **green building**, it rendered environmental discourse measurable through standardized criteria for energy, water, and material efficiency. The concept rapidly gained international traction, and by

1993, the foundation of the *U.S. Green Building Council (USGBC)* marked a decisive moment for the institutionalization of sustainability in design practice, giving rise to the *LEED** certification system. Although methodologies differed, they converged around a common purpose: improving efficiency while reducing environmental and health impacts throughout the building life cycle. These systems, however, largely relied on technological optimization of high-performance envelopes, lighting, and HVAC systems, thus mirroring the energy-driven narrative that dominated the sustainability discourse of that decade ^[21].

By the end of the century, efforts to harmonize these frameworks and facilitate their global adoption led to the creation of the *World Green Building Council (WGBC)* in 1999. The WGBC expanded the original frameworks by integrating life cycle concerns and material databases, enriching the assessment with a wider understanding of environmental performance. This step marked a transition from efficiency-based measures toward a broader view that considered resource extraction, embodied energy, and end-of-life processes. As more national councils joined, the notion of green building matured into a flexible and locally adaptable vision, recognizing that sustainability must respond to each region's climate, culture, and social context. Building on this global movement toward measurable and standardized performance, the next wave of innovation began to focus on energy autonomy, pursuing not only efficiency but complete neutrality in consumption and production. ^[21].

Further efforts to minimize the building industry's devastating consequences for the environment, followed by early discussions started from the 70's in Denmark by Esbensen, Tirben V., and Vagn Korsgaard, which was potentially encouraged by an autonomous seeking generation marked by an oil-crisis, imagined the first solar and passive design that could lead to a zero-energy house. By the turn of the century, however, the new technological wave, fueled by the standardization efforts of green building frameworks, pushed these ambitions further, leading to the consolidation of the **net zero energy building (NZE)** concept. This vision established a new benchmark within sustainable design, in which a highly efficient building balances its annual energy demand with an equivalent supply of renewable energy generated on-site or through local smart-grid systems. Rooted in the straightforward objective of reducing greenhouse gas emissions, NZEBs became closely aligned with international climate commitments such as the *Paris Agreement* and the global carbon neutrality targets set for mid-century ^[22].

Despite their conceptual clarity, the definitions and implementations of NZEBs remain diverse. Across regions, variations exist based on whether the balance is calculated through source energy, site energy, energy costs, or emissions. In Europe, the *Energy Performance of Buildings Directive (EPBD)* introduced in 2010 the term *Nearly Zero-Energy Building (nZEB)*, where a small share of non-renewable is permitted, emphasizing not only high-performance HVAC efficiency but also a greater climate adaptability. While these frameworks have advanced energy performance globally, a final consensus on the methodology remains unresolved, particularly as emerging discussions call for *Zero-Emissions Buildings*, expanding the focus from operational energy toward the embodied energy and life cycle impacts of materials for a necessary evolution towards a truly holistic carbon neutrality ^[22].

* *LEED; Leadership in Energy and Environmental Design, a green building rating system developed to assess building sustainability performance.*

From principles grounded in the field of mathematics, visionaries like Luigi Moretti, who, in 1960, presented the first exhibition of **parametric design** at the Twelfth Milan Triennale. Moretti envisioned architecture conceived as a system composed of multiple interrelated variables, each spatial and structural element determined by a set of measurable parameters. This early vision, though conceptually groundbreaking, surpassed the computational capacities of its time. Decades later, Patrik Schumacher reinterpreted and popularized these ideas under the term *Parametricism* (2009), proposing it as a new global paradigm and trending style of design. Empowered by digital tools and *Visual Programming Languages** (VPL), architects can now translate complex relationships into algorithms capable of enabling the generation and optimization of multiple design options with unprecedented efficiency. The proliferation of big data further expanded the potential of Moretti's early insights, allowing parametric structures to be informed by behavioral datasets in increasingly distinctive ways. What once began as a theoretical approach has evolved into a dominant design language that redefines architectural expression and methodology^[23].

Beyond its formal innovation, parametric design embodies a profound potential for sustainable transformation. By integrating environmental, economic, and quantifiable social parameters into algorithmic models, it allows designers to simulate natural processes, optimize energy performance, and minimize material waste. Adaptive systems, such as facades that respond to climatic variations, illustrate how flexibility and efficiency can coexist within architectural practice. As computational capacities expand and artificial intelligence becomes more embedded in design processes, parametric methods are poised to further enhance circularity and other environmental visions. Ultimately, this approach envisions a future in which architectural form arises not merely from aesthetic intent but from data-driven reasoning that harmonizes structure, performance^[24], and sustainability^[24].

As we have seen in previous cases, the great technological boom of the new century allowed the revisiting of existing visions and encouraged their convergence through new synergies with other environmental approaches. Among these, **biomimetics** stands out as a discipline that, although deeply rooted in humanity's ancestral relationship with the natural world, has gained new relevance with the rise of computational and parametric design tools. Since humanity's earliest endeavors, as seen in the opening of this chapter, we have drawn lessons from natural forms and systems to inform our own inventions, a practice that lies at the very core of biomimetic thinking. As technological complexity evolved, early traces of formal biomimetic principles can even be found in Leonardo da Vinci's anatomical and mechanical studies. However, the term *biomimetics* was formally introduced in the late 1960s by the biophysicist Otto Herbert Schmitt, combining the Greek roots *bios* (life) and *mimesis* (imitation), to define a systematic study of biological analogs for engineering solutions. From that point on, biomimetics grew as a methodological bridge between the biological and the artificial, seeking to consciously reproduce the wisdom of natural processes within human design and technology^[25].

* *visual programming language; visual coding environments that automate and optimize design processes.*

Today, biomimetics applied in architecture expands this principle, viewing nature not only as a form to imitate but also as a broad source of models for adaptation and efficiency. By observing biological systems such as termite mounds, spider webs, beehives, or shell structures, designers have learned how to minimize the use of resources and energy while maximizing structural performance. Geometry in nature, from fractals to the hexagonal logic of honeycombs, demonstrates optimal relationships between matter, strength, and adaptability, inspiring architectural envelopes and climatic regulation systems that self-balance through passive means. Contemporary parametric tools have expanded these possibilities, enabling architects to simulate the complexity and resilience of natural systems and to design forms that respond to environmental conditions rather than resist them. In this sense, biomimetics embodies a cultural paradigm shift; to use nature as measure, not only as inspiration and designing with ecological principles that are adaptive, cyclical, and contextually responsive, turning the accumulated intelligence of evolutionary processes spanning billions of years into a guide for the built environment of the future [25].



FIGURE 2.3.2 – Umbrella for Al Hussein Mosque & Convolvus Flower.
© Biomimicry in Architecture (RIBA Publishing), SL Rasch GmbH 2000.

In a divergent approach, one of the first publications of the new era that resonated deeply with an emerging shift in values was undoubtedly *Cradle to Cradle* (2002) [26] by William McDonough and Michael Braungart. They questioned the industrial practices inherited from the past century, conceived under the belief of an endless supply of natural “capital,” which no longer aligns with our current understanding of the planet’s limits. Their critique targeted the linear model of production and consumption that takes a product from its origin, or cradle, directly to its disposal, or grave, generating immense waste and pollution through synthetic compounds difficult to reintegrate into the environment. Instead of this extractive logic, they proposed a “law of return,” not as an obligation, but as a natural ethic of reciprocity. By proposing a new principle that turns waste into “food”, moving products from cradle to a new cradle, they reimagined that industry could work as part of nature’s metabolism, where human activity can be restorative rather than merely less harmful [26].

This approach of **circularity** replaced the traditional “reduce, reuse, recycle” mindset with a deeper reintegration of materials into closed loops with nature. Its call was not to be *less bad*, but to do things *right*, since small optimizations within flawed systems only perpetuate harm. The perseverance of this vision has led to extensive research and the creation of material databases that make the method accessible to designers, engineers, and companies seeking to coexist more responsibly with their environment. Their vision has expanded widely and is now a model for collaborative, distributed development, which decentralizes decision-making, where the prosperity of human systems depends on the health and reciprocity of the environments they inhabit [26].

Thinking beyond materials, contemporary circular thinking encompasses new visions that integrate environmental needs with economic and social frameworks, linking multiple actors toward a shared goal of regenerative and equitable development. Such is the distinctive work of economist Kate Raworth, who in 2017 published the revolutionary book *Doughnut Economics*, challenging the outdated assumptions of limitless growth inherited from industrial thinking. In this new circular interpretation, economic systems are framed within ecological ceilings and social foundations, aiming to ensure that no one falls short on life’s essentials while collectively avoiding overshoot of the planet’s life-supporting systems. Raworth’s model, visualized through a doughnut-shaped diagram, exposes the imbalance of an economy addicted to expansion and calls instead for economies that thrive in balance, regenerative by design and distributive by nature. This perspective aligns closely with the values of circular design, inviting us to redefine prosperity not by endless growth, but by the capacity to sustain life within the limits of our shared home [27].

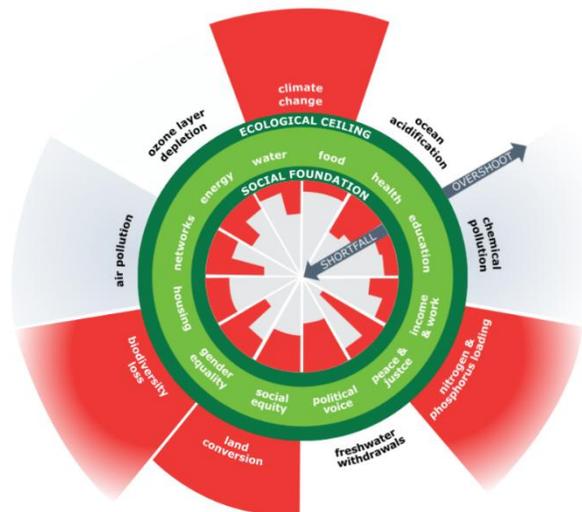


FIGURE 2.3.1 – “The Doughnut of social and planetary boundaries” [27].

Following the vision of circularity, other perspectives that had long existed resurfaced under renewed attention, re-labeled as *bioconstruction*, as it is most named in Hispanic regions. Although its popularization began in the late 1980s, it converged with the discourse of circularity in the following decades. Emerging as a countercultural response to the over-industrialized construction techniques imposed on developing countries as symbols of modernity, bioconstruction questioned the environmental and social costs of such imported models. These industrial methods, characterized by complex manufacturing chains, intensive energy use, and the long-distance transport of materials, produced buildings saturated with toxic *Volatile Organic Compounds** (VOCs) and left a deep ecological footprint throughout their life cycle ^[28].

In contrast, *bioconstruction*, also referred to as *natural construction*, finds in vernacular wisdom the principles for building in harmony with the environment. Drawing on locally available, low-impact materials such as earth, stone, straw bale, and plant fibers, it promotes structures that are climatically adapted and capable of reintegrating into the natural cycle after fulfilling their human function. This practice not only reduces environmental harm but also supports local economies by encouraging the use of regional resources and creating local employment. Moreover, it revalues ethnobotanical knowledge, recognizing the importance of biodiversity and the traditional understanding of native species. Ultimately, bioconstruction represents a return to building at a human scale, an architecture that aligns ecological respect with social well-being, distancing itself from consumerism and seeking equilibrium within natural cycles ^[28].

In close relation to bioconstruction, another term that can be found and requires clarification is *eco-construction*, which appeared informally, mainly in French publications. Although its definition lacks full consensus, it essentially refers to construction practices that integrate environmental considerations throughout the entire life cycle of a project, from conception to realization. In this perspective, eco-construction prioritizes the use of biosourced, geosourced, recycled, or reused materials and seeks to limit energy consumption, waste generation, and the depletion of non-renewable resources. Beyond material choice, it also implies a return to context-sensitive, vernacular principles, designing with the local climate, culture, and available resources in mind. While adapting these to contemporary standards in France, this approach has been formalized through certification systems such as *Haute Qualité Environnementale (HQE)*, which emphasizes harmony between buildings and their environment, responsible material selection, and the reduction of site pollution ^[29].

Closely linked to this idea but built upon a standardization focus, the term **eco-design** gained strength in the European context following the 2009 *Eco-design Directive*, to encompass appliances such as heating and cooling equipment, lighting, household devices, and other systems with significant energy use. Eco-design emerged as a methodological framework for integrating environmental considerations throughout the

* volatile organic compounds; carbon-based chemicals emitted as gases from synthetic materials, often causing indoor air pollution and health risks.

design and development process, with the aim of minimizing adverse impacts across the full life cycle of a product or building. Defined under *ISO 14006:2011*, it places environmental responsibility at the same level of importance as efficiency, aesthetics, cost, and functionality. In recent decades, it has been widely adopted in industrial, engineering, and architectural design as a tool to achieve sustainability goals, such as energy efficiency and waste reduction. By aligning ecological and economic aspects on the dual meaning of the prefix “eco”, this approach reflects the shift that European markets have shown with a growing awareness of environmental responsibility, with consumers now ranking ecological impact among the most important factors in their purchasing decisions. This cultural and economic transition signals a broader commitment to sustainability, where design choices are increasingly guided by ecological awareness rather than mere consumption^[30].

This cultural shift toward awareness of environmental responsibility in our consumption choices reflects a broader reassessment of technological products’ implications and precisely how they are integrated into the built environment. Re-opening the doors for already started debates, that now gain traction together with environmental views from circularity to eco-design. Building on the conversation initiated by Bernard Rudofsky’s *Architecture Without Architects* exhibition at MoMA in 1967, this vision places a forceful critic to the overreliance on complex technological systems, from over-mechanized climatization to fully automated buildings that, as seen in the high-tech movement, transformed technology into both aesthetic expression and functional dependence. In response, the term **low-tech** came to be used to signal a deliberate simplicity and a shift toward reliance on accessible, repairable, and locally maintainable technologies rather than on complex, resource-intensive systems. This dialogue now seems more relevant than before, as today’s designers question whether the logic of perpetual technological upgrading, high-performance systems, or optimized industrial cycles can truly meet sustainable goals. Low-tech questions the technological excesses embedded in modern construction and revalues the ingenuity of simple design solutions rooted in vernacular knowledge and pre-industrial craft, advocating the thoughtful and proportionate use of technologies and prioritizing adaptability and repairability^[31].

Extending the principles of vernacular construction into a broader ecological and social framework, low-tech intersects with what some authors refer to as *Lo-TEK*^[31], a variation of it that draws from Traditional Ecological Knowledge (TEK) and indigenous technologies as models for sustainable and regenerative design. These systems, developed through generations of observation and adaptation, demonstrate how human ingenuity can operate in symbiosis with natural processes rather than in opposition to them. In this sense, low-tech stands as both a philosophical and practical response to the environmental and social costs of over-industrialization. It reframes technology not as a symbol of progress, but as a tool for coexistence, local, handmade, adaptable, and capable of sustaining life rather than depleting it. In this regard, the low-tech approach also aligns closely with the concept of *Nature-based solutions (NBS)*, which advocates harnessing living systems, such as

vegetation, water, soil, or microclimates, to address environmental and societal challenges, endorsed by the European Commission and UN as key climate adaptation strategies. Both perspectives emphasize working with nature rather than against it, prioritizing ecological regeneration over technological substitution. By merging innovation with ancestral wisdom, low-tech visions expand the definition of technology itself, proposing a path toward architectures and infrastructures that are not only efficient and affordable but also deeply attuned to the rhythms and limits of the planet [31][32].

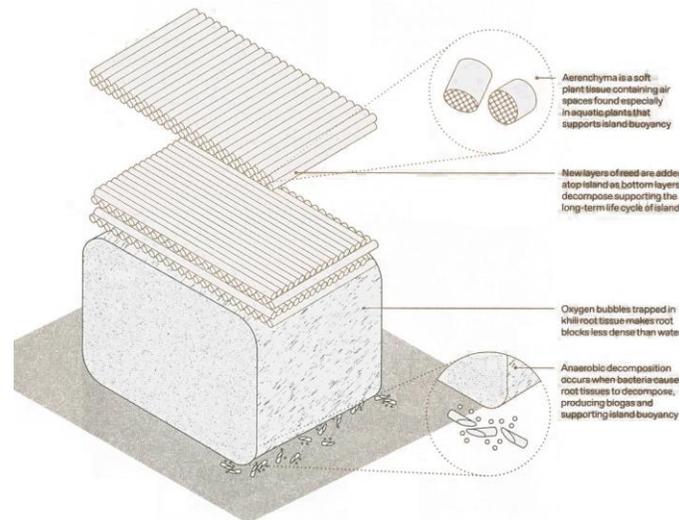


FIGURE 2.3.3 – Brick Module, supported by organic processes. [31]p278

Despite the promising principles of low-tech, its implementation has faced several barriers that have limited larger-scale adoption. Regulatory frameworks still tend to favor standardized materials and methods, often rendering vernacular or bio-based systems “irregular” in legal terms. Economic and cultural factors add further resistance, as such approaches may require greater labor input and a shift in user habits toward more participatory, less automated forms of living. Moreover, the radical image of low-tech and the impression of a reference to declination have made it less appealing to clients and policymakers. In response, a new term has been introduced, *right-tech* or *just-tech*, intended to present a more balanced stance. These emerging notions call for *techno-discernment*, to neither glorify high-tech dependence nor idealize low-tech purism, but rather seek an equilibrium, using technology where it is truly necessary and refraining where it is not. They propose bridging bio-based construction and circular principles with semi-standardized systems that can be integrated into existing urban networks, making ecological transition more attainable within current industrial realities [32].

Nearly a century after the Bauhaus’ movement, which sought “adequate, affordable, and scalable” design for its time, right-tech thinking revives this spirit of synthesis, combining craftsmanship, industry, and ecology to address contemporary environmental and societal challenges. In this way, a broader implementation of right-tech strategies directly addresses

the hidden costs of our high-tech dependency, the environmental degradation and geopolitical tensions associated with the extraction of rare minerals, the growing challenge of non-recyclable electronic waste, and the rebound effect, in which efficiency gains ultimately encourage greater consumption. By promoting a more responsible use of materials and energy, prioritizing the refurbishment, renovation, and transformation of existing buildings rather than pursuing new construction whenever possible. In shifting landscape, architects are rethinking their role beyond the mere production of objects, taking on a civic responsibility to guide adaptive and resource-conscious processes that respond to collective needs. Within this context, such as Baumschlager Eberle Architekten's *22–26 building* in Austria demonstrate how minimal technology and intelligent passive design can redefine comfort by encouraging user adaptability rather than mechanical control. These approaches open a broader cultural conversation about agency and behavior, inviting architects to foster environments that empower people to live more consciously within planetary limits, an idea that leads to our next emerging discourse ^{[32][33]}.

Converging ideas once again appear, this time emerging in the 1990s and gaining wider recognition with Thomas Princen's *The Logic of Sufficiency* (2005) ^[34]. The term **sufficiency** began to circulate as a counterpoint to efficiency, marking the historical need to redefine the notion of limits and “enoughness,” which had long been dissolved within an ever-expanding market logic. As Kate Raworth's circular vision also reflects, modern economies have been built on the illusion of endless growth, in which technological innovation promises that efficiency alone can offset resource depletion. In contrast, sufficiency establishes a moral and ecological boundary, a principle that connects moderation, prudence, and fairness with environmental and social integrity. It calls attention to the risks of excess: when present gains undermine future well-being, when resource use surpasses regenerative capacities, or when private rewards are built upon collective costs ^[34].

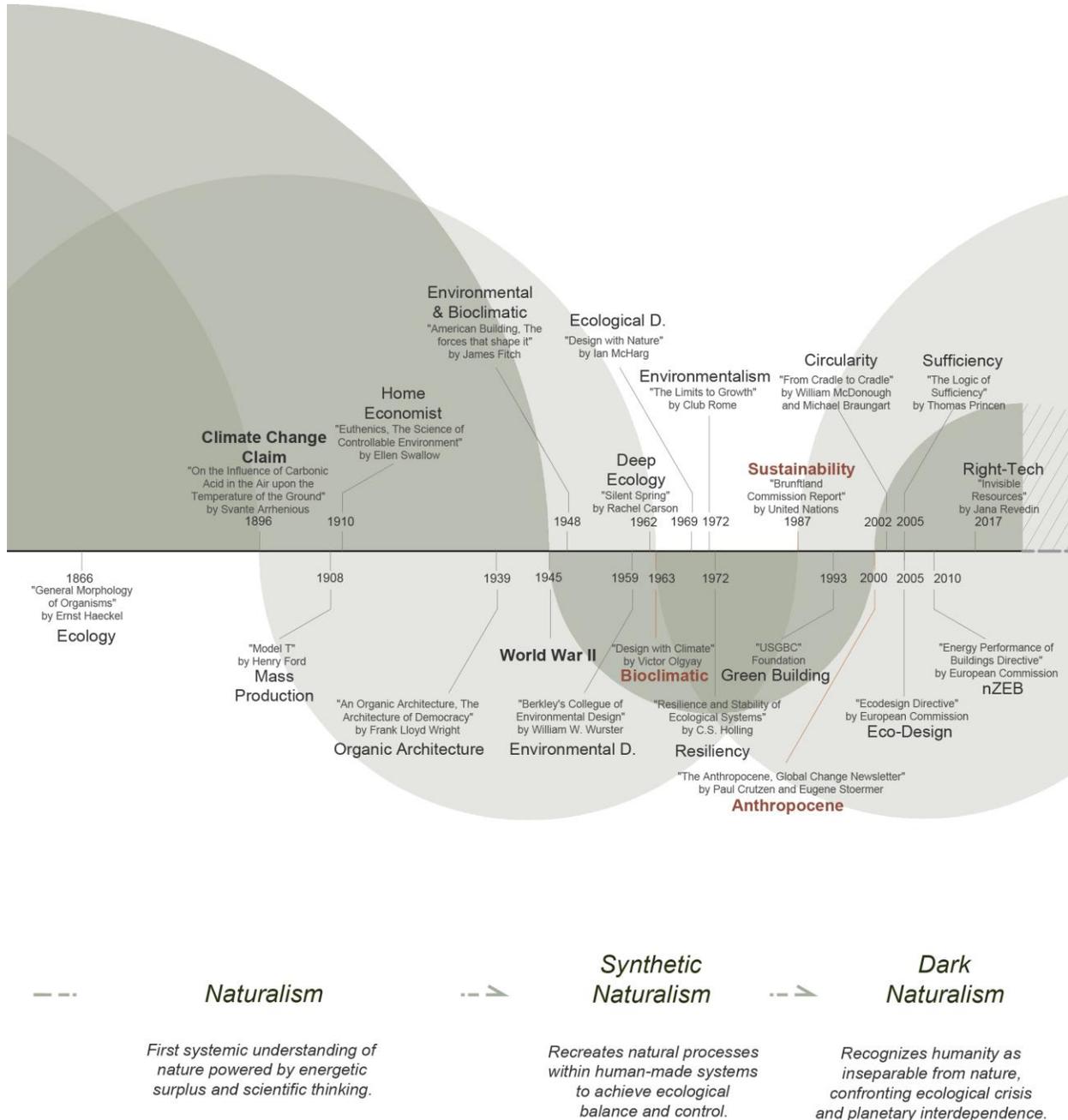
Within architecture, the discourse on sustainability has become increasingly dominated by efficiency as the ultimate metric, measuring everything from material production to energy performance and even planning processes themselves. Yet, as several scholars argue, this fixation risks contradicting the very principles of sustainability. Efficiency, while valuable, is inherently relative: it can optimize systems that remain environmentally destructive or socially unjust. A process can be highly efficient yet profoundly unequal. Moreover, when treated as an end in itself, efficiency reinforces the same techno-utopian faith that has driven ecological overshoot, trusting that innovation will indefinitely resolve the crises it helped create. In this sense, sufficiency reclaims sustainability's ethical core, reminding us that technological progress must operate within ecological limits and be guided by notions of equity and restraint rather than perpetual acceleration. As environmental pressures intensify and the limitations of efficiency-centered thinking become increasingly evident, sufficiency emerges not only as a critique but as a necessary complement to efficiency, one capable of reorienting design and societal expectations toward what is truly needed rather than what can merely be optimized ^[35].

As the sustainable agenda continues to expand, new visions have emerged, and the last one considered relevant for disambiguation in recent decades is the so-called **resilient design**. Introduced originally by the Canadian ecologist Crawford Stanley Holling in 1973 in his paper *Resilience and Stability of Ecological Systems*, it defines resilience as the capacity of ecological systems to absorb disturbances, reorganize, and maintain their essential functions. In architecture and urbanism, the concept has been reinterpreted as a strategy for adaptation in the face of growing environmental volatility and uncertainty. Unlike other visions that focused on speculative means of minimizing environmental impact, resilience frames itself as a direct response to an ongoing crisis, seeking to manage and adapt rather than merely prevent disruption. Fueled by data-driven decision-making and supported by cybernetic technologies, simulation models, and ecosystem service frameworks, resilient design has proven to be a valuable discipline for anticipating, adapting, and mitigating risk. Its design strategies are often translated into green and permeable infrastructures, urban parks, wetlands, or sponge systems, capable of absorbing stormwater, remediating air pollution, and moderating extreme temperatures, turning the city itself into a flexible and self-regulating organism. As a result, many governments have adopted resilience as a guiding political discourse, enabling planning mechanisms that rely on complex probability and vulnerability data to prepare for future shocks ^[8].

Moreover, as we have widely seen, contemporary design visions no longer act within isolated dimensions of sustainability, and such is the case of resilient design, which merges spatial planning, ecology, and governance under a new epistemology that replaces the notion of equilibrium with the dynamic capacity for continuous adjustment. Yet, this framework has not been exempt from critique. Theorists such as Ross Exo Adams argue that resilient urbanism entails the politicization of communities and the normalization of permanent crisis, transforming resilience into a governing logic that preserves existing production systems rather than transforming them. Likewise, Maura Benegiamo emphasizes that resilience often privileges the technical reconstruction of infrastructures while downplaying the social and ecological roots of vulnerability. Despite these tensions, resilient design has nonetheless become a fertile ground for experimentation, advancing integrative models such as the *sponge city* or *Resilience by Design* initiatives, which demonstrate that adaptive systems can also foster environmental justice and social participation. By dismantling binary oppositions such as waste/resource or inside/outside, this paradigm proposes new ways to monitor, understand, and represent the complexity of natural processes, offering, perhaps, one of the most promising frameworks for envisioning coexistence in a time of instability ^[8].

DIAGRAM 2.C – Modern Timeline of Sustainable Paradigms.

This timeline traces the key publications and milestones that have shaped the conceptual evolution of sustainability in architecture over the past decades.



It illustrates my interpretation of the multiple paradigms that have emerged, overlapped, and transformed over time, revealing that contemporary sustainable architecture is not defined by a single vision but by the coexistence and interaction of diverse approaches.

2.4 Performance and Purpose

As we have seen, the meaning of sustainable architecture has always been dynamic, continuously expanding both before and after its formal definition as an approach that seeks to safeguard the well-being of the present without compromising the ecological, social, or economic capacities on which future generations depend. However, the boundaries and links among its multiple visions are far from fixed, and because this plurality of voices is anchored in the core of sustainability, it will often draw on several of them at once. What this incomplete map reveals is that the conceptual pursuit of a respectful relationship with our environment is not static but in constant evolution, adapting to each context, each challenge, and even each project. It is not a single discipline, but rather a living field shaped by experimentation, reinterpretation, and response to change.

Modern sustainability studies, however, emerged from the growing global crises of the late twentieth century and were founded on earlier, scientifically driven disciplines characteristic of *synthetic naturalism*, such as bioclimatic and environmental design. This paradigm has evolved from the activist vanguard of the 1970s and 1980s into a consolidated, institutionalized field, taught in universities, applied in studios, and promoted by international organizations worldwide. The rise of environmental awareness, propelled by the daily evidence of global emergencies, has given the discourse on sustainability broader social resonance and sympathy for so-called “green” visions. Yet this expansion has also been accompanied by a growing interest in capitalizing on sustainability. Without intending to render a simplistic judgment, it must be acknowledged that this process has biased the sustainable agenda through economic and political interests. Green capitalism, as some theorists argue, functionalizes ecosystems through logics of efficiency, performance, and metric data, promoting measurable agendas that can often obscure deeper ethical, social, and cultural dimensions ^{[8][13]}.

Since the Renaissance, the scientific method has promoted the belief that rational thinking and technology, as its most exemplary tool, were the proper means to explain and dominate reality. Paradoxically, four centuries later, we remain under the influence of this same ethos*, only now beginning to question this positivist understanding of the world. The reductionist approach inherent in most design guidelines and sustainability standards has encouraged the proliferation of regulations that often overlook the many contextual issues surrounding sustainable design. The widespread assumption that the simple use of “green” technology guarantees a sustainable building is unconvincing. In doing so, it downplays broader, more complex factors, such as favoring local economies, empowering communities, or reshaping social hierarchies. Aspects like aesthetics, identity, and cultural continuity are often dismissed as non-quantifiable and fade in front of overwhelming economic and performative interests. Technologies are only part of the picture; they can support sustainable thinking but cannot define it in its entirety ^{[12][13][18]}.

* *ethos*; from the Greek meaning “character”, refers to the guiding beliefs, values, or moral spirit that characterize a community, culture, or era.

Bridging the gap between sustainability initiatives and economic growth has undoubtedly opened important opportunities and encouraged innovation. However, ethical responsibilities have little to do with these performance metrics, and cultural values cannot be rendered efficient; in this sense, an entire dimension of sustainability is being overlooked. The existing obsession with metrics, facts, and measurable truths as ultimate indicators of reliability conceals their own inherent limits; relativity, bias, and the fragility of our instruments of measure. While this quantifiable approach has undeniably contributed to advances in energy efficiency, water conservation, carbon reduction, and material health, it has simultaneously neglected the more intangible aspects that define a truly sustainable inhabitation. Beyond numbers lies the necessity of engaging with the unquantifiable, the dimensions of behavior, perception, and meaning that bring balance, cultural identity, and delight to the built environment. Only by integrating these qualitative aspects can sustainability move toward a holistic and genuinely human-centered paradigm ^{[8][36]}.

Defining sustainability has proven elusive, as it has become a term of convenience, a desirable attribute that almost everything aspires to possess. Its plural and adaptable nature makes it equally open to creative interpretation and to misuse, often reduced to a fashionable label that renders anything “green.” The abundance of definitions and approaches has turned sustainability into a vast container, one that can hold nearly anything, but whose contents should be continuously re-examined. Understanding what is truly being placed inside and discerning what remains relevant or compatible becomes essential. A wider notion of sustainability is needed, one that embraces its full range of dimensions while critically filtering what belongs within it. Through the historical perspective developed in this chapter, we hope to have slightly reduced that uncertainty and slightly illuminated the complexity behind what the term sustains.

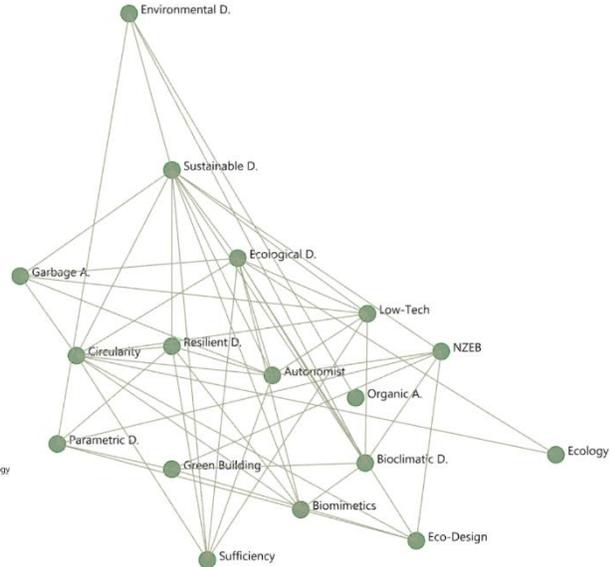
Building on the previous discussion of sustainability’s prevailing quantitative focus, and without falling into simplistic dichotomies, we propose to work alongside this well-established analytical branch while complementing it with a qualitative approach. Such a perspective acknowledges plurality, contextual sensitivity, and the interrelation of values, seeking to recover the many dimensions that contemporary practice often overlooks ^[36]. By schematizing these relationships and contrasting them with the evaluation methods used in sustainable architecture practice, the following chapters examine how contemporary environmental performance indicators and their associated toolchains shape design decisions. Through this comparison, the thesis identifies where current assessment frameworks align with, overlook, or distort the broader visions of sustainability, revealing concrete gaps and opportunities to strengthen the environmental, qualitative, and conceptual dimensions of sustainable architectural practice.

DIAGRAM 2.D – Semantic Network of Sustainable Paradigms.

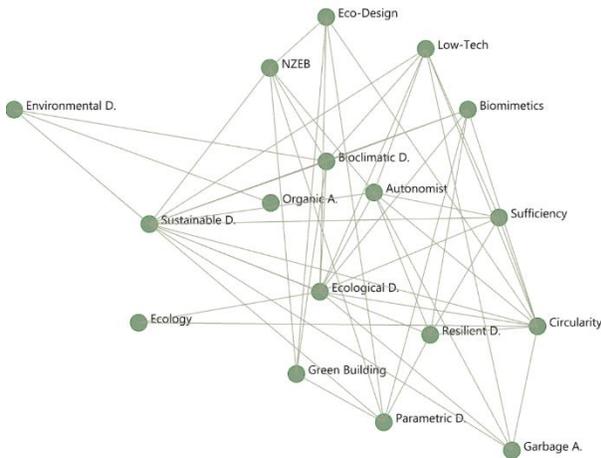
The interrelation studies were developed through *Grasshopper* simulations using the *Kangaroo solver*, applying rule-based connections among the different sustainability visions. Multiple iterations were generated to explore alternative configurations, all of which were potentially valid.



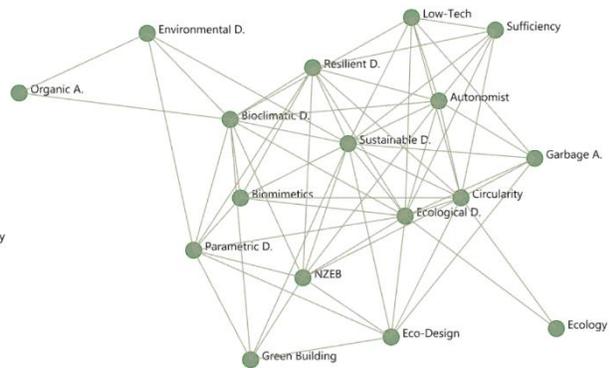
2.D.1 – Network with high priority links only.



2.D.2 – Network with full set of linking rules.



2.D.3 – Network with different set of linking rules.

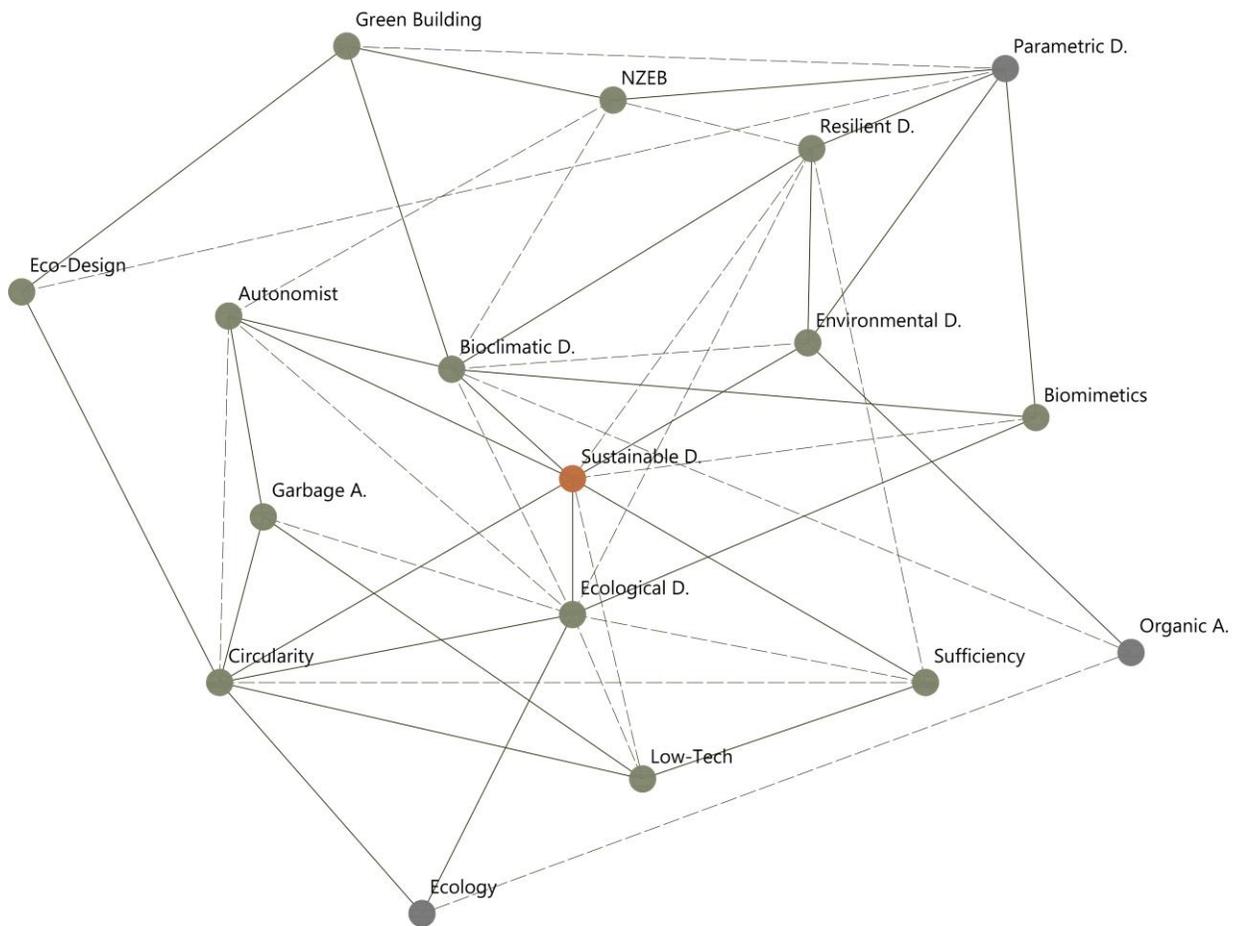


2.D.4 – Network with different seed of points.

Illustrating that sustainable design is not always positioned at the center of the discourse. The process revealed that a wide range of paradigms complement one another, often overlapping to the extent that certain terms can be used interchangeably, reflecting the fluid and interconnected nature of contemporary sustainability thought.

The diagram evolved into the version the author considered most convincing, as clusters of views began to delineate clearer axes that shape the main dimensions of sustainability in recent decades. These configurations were then manually refined to distinguish primary from secondary connections.

The final mapping reveals the interrelations among paradigms, offering a clustered reading of knowledge aligned with contemporary interpretations of *Dark Naturalism*, and aims to outline a qualitative framework that complements prevailing quantitative approaches



2.D.5 – Final Network with manual modifications.

Chapter 3

Environmental Performance Indicators

“How could intelligent beings seek to control a few species by a method that contaminated the entire environment and threat their own kind?”

-Rachel Carson

3.1 Fellow Frameworks

As we have seen, sustainable architecture has evolved from an ancient, often unconscious directing force into a well-established discipline shaped by the activism and environmental hazards of the twentieth century. Once a clearer notion of sustainability in architecture was defined, the trajectory led to the need for establishing metrics to compare results, and systems were required to ensure accuracy in assessing the impact of construction on its surroundings. Today’s alarming statistics account for the building sector as being responsible for nearly forty percent of global greenhouse gas emissions (*figure 3.1.1*), an undeniable responsibility that falls on the designers behind this burden.

These methodologies operate within the domain of facticities, where measurable outcomes offer a clearer understanding of the environmental benefits of certain practices, presenting them as the most promising strategy to confront the urgency of the climatic crisis. These systems, however, have become increasingly diverse since the early efforts at green building standardization in the 1990s, with a range of frameworks accounting for a variety of factors. In this context, the aim of this chapter is to provide a clear overview and criteria for selecting the most relevant among the so-called environmental performance indicators, to continue with a qualitative breakdown of its implications ^[36].

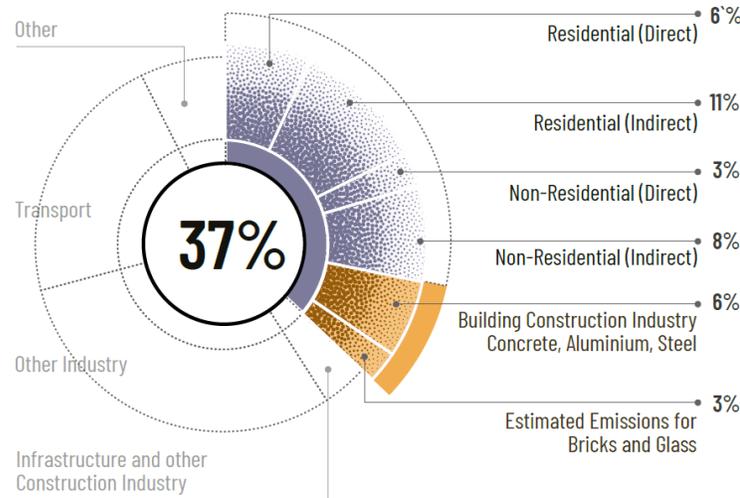


FIGURE 3.1.1 – Global Carbon Emissions from the Built Environment sector.

© UN Environment Programme, *Building Materials and Climate 2021*.

As one of the key outcomes of the World Summit on Environment and Development held in Rio de Janeiro in 1992, the United Nations Commission on Sustainable Development (UNCSD) was established to monitor countries' progress in developing and applying sustainable development indicators. This initiative evolved from earlier debates on industrial pollution tracking during the 1970s, when commonly used measures such as Gross National Product or isolated resource and pollution statistics proved inadequate to convey the complexity of sustainability. In response, *Agenda 21* emphasized the need to strengthen information for decision-making by bridging the persistent data gap between developed and developing regions and by improving the quality, coherence, and accessibility of environmental information, recognizing that informed governance relies on reliable, comparable, and regularly updated datasets capable of translating scientific knowledge into practical guidance for policy and design. The call for harmonization at national and international levels aimed to build a coherent language of measurement that could support both governmental and institutional accountability. ^{[37][38]}

Building on these objectives, the UNCSD published *Indicators of Sustainable Development: Framework and Methodologies* in 1996, consolidating a shared foundation for indicator use and standardization. This document introduced the term Environmental Performance Indicators (EPIS), defining them as measures of the interaction between an organization and its environment, focused on inputs, outputs, and impacts. It also proposed a preliminary set of 134 indicators, structured across social, economic, environmental, and institutional dimensions. Following extensive testing in participating countries, a subsequent revision in 2001 refined the list and reduced it to 58 indicators, representing the last official review by the UN (*figure 3.1.2*). These indicators were conceived not as fixed metrics but as evolving tools*, translating complex physical and social knowledge into accessible information to guide sustainable decision-making at multiple levels ^[37].

* tool; the computational or methodological instrument employed to generate, model, or quantify an indicator.

SOCIAL		
Theme	Sub-theme	Indicator
Equity	Poverty (3)	Percent of Population Living below Poverty Line
		Gini Index of Income Inequality
		Unemployment Rate
	Gender Equality (24)	Ratio of Average Female Wage to Male Wage
Health (6)	Nutritional Status	Nutritional Status of Children
	Mortality	Mortality Rate Under 5 Years Old
		Life Expectancy at Birth
	Sanitation	Percent of Population with Adequate Sewage Disposal Facilities
	Drinking Water	Population with Access to Safe Drinking Water
	Healthcare Delivery	Percent of Population with Access to Primary Health Care Facilities
Immunization Against Infectious Childhood Diseases		
Contraceptive Prevalence Rate		
Education (36)	Education Level	Secondary or Primary School Completion Ratio
	Literacy	Adult Literacy Rate
Housing (7)	Living Conditions	Floor Area per Person
Security	Crime (36, 24)	Number of Recorded Crimes per 100,000 Population
Population (5)	Population Change	Population Growth Rate
		Population of Urban Formal and Informal Settlements
ENVIRONMENTAL		
Theme	Sub-theme	Indicator
Atmosphere (9)	Climate Change	Emissions of Greenhouse Gases
	Ozone Layer Depletion	Consumption of Ozone Depleting Substances
	Air Quality	Ambient Concentration of Air Pollutants in Urban Areas
Land (10)	Agriculture (14)	Arable and Permanent Crop Land Area
		Use of Fertilizers
		Use of Agricultural Pesticides
	Forests (11)	Forest Area as a Percent of Land Area
		Wood Harvesting Intensity
Desertification (12)	Land Affected by Desertification	
Urbanization (7)	Area of Urban Formal and Informal Settlements	
Oceans, Seas and Coasts (17)	Coastal Zone	Algae Concentration in Coastal Waters
	Fisheries	Percent of Total Population Living in Coastal Areas
		Annual Catch by Major Species
Fresh Water (18)	Water Quantity	Annual Withdrawal of Ground and Surface Water as a Percent of Total Available Water
	Water Quality	BOD in Water Bodies
		Concentration of Faecal Coliform in Freshwater
Biodiversity (15)	Ecosystem	Area of Selected Key Ecosystems
		Protected Area as a % of Total Area
	Species	Abundance of Selected Key Species
ECONOMIC		
Theme	Sub-theme	Indicator
Economic Structure (2)	Economic Performance	GDP per Capita
		Investment Share in GDP
	Trade	Balance of Trade in Goods and Services
	Financial Status (33)	Debt to GNP Ratio
Total ODA Given or Received as a Percent of GNP		
Consumption and Production Patterns (4)	Material Consumption	Intensity of Material Use
	Energy Use	Annual Energy Consumption per Capita
		Share of Consumption of Renewable Energy Resources
		Intensity of Energy Use
	Waste Generation and Management (19-22)	Generation of Industrial and Municipal Solid Waste
		Generation of Hazardous Waste
		Generation of Radioactive Waste
Waste Recycling and Reuse		
Transportation	Distance Traveled per Capita by Mode of Transport	

FIGURE 3.1.2 – Theme Indicator Framework.

© UN Commission on Sustainable Development, Ninth Session 2001^[37].

After this extensive testing of the initial set of indicators, a revised approach was introduced in 1999, this time presented by the International Organization for Standardization (ISO). Building on the groundwork established by the United Nations, ISO transformed this policy framework of macro-level decision-making tools into an operational standard tailored for environmental management within organizations and companies. The resulting document, ISO 14031:1999 – *Environmental Performance Evaluation: Guidelines (EPE)*, did not prescribe a fixed list of indicators; instead, it proposed a dynamic structure organized into three categories: Operational Performance Indicators (OPIs), Management Performance Indicators (MPIs), and Environmental Condition Indicators (ECIs) (figure 3.1.3). Designed as an internal and continuous process, the EPE provided reliable and verifiable information to determine whether an organization’s environmental performance met its own defined objectives, while identifying areas for improvement over time. It is important to note that these indicators are intended for assessing the performance of organizations rather than individual building projects; however, their logic and structure influenced later project-level frameworks in the building sector. By shifting the focus toward micro-level management and life-cycle perspectives, this standard effectively bridged institutional policy goals and the emerging field of green building standards^[39].

The latest update to ISO 14031, published in 2021 as the third edition, has evolved from an organization-centric tool into a dynamic, digital, and globally aligned framework. Building on the foundations of the United Nations work and the ISO 14000 family of standards, this revision reinforces coherence with complementary sustainability approaches, including Life Cycle Assessment (LCA), environmental labelling and declarations, circular economy strategies, and net-zero frameworks. It retains the core classification of Operational, Management and Environmental Indicators (OPI/MPi/ECI), while broadening its perspective to encompass the wider supply chain, stakeholder participation, and external reporting, introducing a risk-based thinking for a new materiality assessment based on the degree of significance to the organization, in order to determine the selection and prioritization of the EPIs used on the selection^{[40][41]}.

The new edition also integrates advanced tools for data analysis and communication, including digital twins, AI-based predictive EPIs, anomaly detection systems, IoT protocols, API integration, and blockchain mechanisms for transparency and traceability. By aligning environmental performance with the latest UN Agenda and the Paris-Agreement decarbonization pathways, ISO 14031:2021 redefines Environmental Performance Evaluation not as an isolated corporate exercise but as a direct contribution to global climate and development objectives. The standard explicitly connects its indicators to the Sustainable Development Goals (SDGs), illustrating examples of links between EPIs and specific SDGs, ensuring the standard’s ongoing relevance within contemporary sustainability agendas with special impact on clean energy and water, responsible consumption, sustainable cities, and climate action (figure 3.1.3)^{[40][41]}.

ISO 14031:2021 Environmental Performance Evaluation (EPE)		
OPIs	MPIs	ECIs
– materials used per unit of product	– effectiveness of management systems or programmes	– concentration of contaminants in ambient air
– processed, recycled or reused materials used	– benefits and costs of environmental management to the organization	– measured reduction of GHGs
– water per unit of product	– success of the prevention of pollution initiatives	– concentration of contaminants in groundwater or surface water
– energy used per year or per unit of product	– number of environmental suggestions submitted by employees	– change in water levels
– each type of energy used	– employees knowledge of the organization's environmental issues	– concentration of contaminants in surface soils
– percentage of parts designed for disassembly, recycling and reuse	– time to respond environmental incidents	– paved and non-fertile area in defined local zone
– the average fleet carbon dioxide equivalent per unit driven	– return of investment for environmental improvement projects	– number of total flora species in a defined local area
– the durability of the product	– savings in resources, prevention of pollution or waste recycling	– population of a particular animal species within a defined distance
– the quantity of waste per unit	– inquiries about environmental related matters	– harmful noise levels
– specific emissions per year	– number of sustainability partnerships	– population density in the local or regional area
INVOLVED SDGs	6. Clean Water and Sanitation	6. Clean Water and Sanitation
	7. Affordable and Clean Energy	
	11. Sustainable Cities and Communities	11. Sustainable Cities and Communities
	12. Responsible Consumption and Production	
		13. Climate Action
	17. Partnerships for the Goals	

FIGURE 3.1.3 – Examples of EPE Indicators.

© ISO 2021, 14031 Environmental Performance Evaluation ^[41].

With the growing awareness of environmental impacts and the search for reliable methods to assess them, another framework began to gain traction. Originating from early attempts in the 1970s, from Coca-Cola Company’s first systematic study to analyse different beverage container materials, quantifying costs and environmental impacts of their products, emerged the basis of a new approach. Later in 1990, the international organisation The Society of Environmental Toxicology and Chemistry formalized the idea by proposing a Life Cycle Assessment (**LCA**), as a systematic method to examine impacts across all stages of a system’s life. This aligned with the growing discourse on circularity, offering a framework for analyzing cradle-to-grave and cradle-to-cradle processes, including raw material extraction, manufacturing, use, and end-of-life recovery. The method was soon consolidated within the ISO 14000 series, first standardized in 1993 and later refined into the current ISO 14040:2006 and ISO 14044:2006, which outline the principles, framework, and methodological requirements for conducting an LCA. Its formalization marked a critical shift to understanding the full chain of a product before and after it is consumed, and the increasing pressure industries faced to demonstrate verifiable sustainability claims positioned LCA as a foundational tool for a new age environmental assessment ^{[42][43]}.

LCA has proven particularly effective in identifying opportunities to improve environmental performance across different stages of a product’s lifespan, guiding strategic decision-making, and supporting transparent communication in environmental labeling and declarations. According to ISO methodology, LCA consists of four phases, starting with a clear definition of the goal and scope, establishing system boundaries, and specifying the required level of detail. Secondly, a life cycle inventory phase, in which all relevant input and output flows are compiled, is followed by a life cycle impact assessment, which adds interpretive layers to understand the environmental relevance of these flows (figure 3.1.4). Finally, an interpretation phase, in which results are evaluated against the study's goals and used to inform decisions [43].

Today, LCA has expanded far beyond its original form and is regarded as a cutting-edge evaluation tool in fields ranging from manufacturing to energy systems and the built environment. Multiple specialized variants, including new hybrid methodologies, life cycle costing (LCC), social LCA (SLCA), and full life cycle sustainability assessment (LCSA), extend the method toward economic and social dimensions, addressing different analytical needs, and reinforcing its role as a central instrument for multidimensional sustainability evaluation. Furthermore, while growing critiques have pointed out limitations related to boundary choices, data quality, and the lack of temporal and spatial resolution, cutting edge technologies integrate approaches now combining LCA with GIS for resource potential assessment and spatial planning, or with tools such as big data analytics, IoT sensors, artificial intelligence, and blockchain to enhance data acquisition, real-time modeling, and traceability. As a result, contemporary LCA is progressively shifting from static assessments toward dynamic, system-wide analyses that better reflect the complexities of modern products, technologies, and buildings [42].

Impact category	Impact category Indicator (unit of measure)	Description
 Climate change, total	Radiative forcing as global warming potential – GWP100 (kg CO ₂ eq)	Increase in the average global temperature resulting from greenhouse gas emissions (GtG)
 Ozone depletion	Ozone Depletion Potential – ODP (kg CFC-11 eq)	Depletion of the stratospheric ozone layer protecting from hazardous ultraviolet radiation
 Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	Impact on human health caused by absorbing substances through the air, water, and soil. Direct effects of products on humans are not measured
 Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	
 Particulate matter	Impact on human health (disease incidence)	Impact on human health caused by particulate matter emissions and its precursors (e.g. sulfur and nitrogen oxides)
 Ionising radiation, human health	Human exposure efficiency relative to U-235 (kBq U-235 eq)	Impact of exposure to ionising radiations on human health
 Photochemical ozone formation, human health	Tropospheric ozone concentration increase (kg NMVOC eq)	Potential of harmful tropospheric ozone formation ("summer smog") from air emissions
 Acidification	Accumulated Exceedance – AE (mol H ⁺ eq)	Acidification from air, water, and soil emissions (primarily sulfur compounds) mainly due to combustion processes in electricity generation, heating, and transport

Impact category	Impact category Indicator (unit of measure)	Description
 Eutrophication, terrestrial	Accumulated Exceedance – AE (mol N eq)	Eutrophication and potential impact on ecosystems caused by nitrogen and phosphorous emissions mainly due to fertilizers, combustion, sewage systems
 Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (kg P eq)	
 Eutrophication, marine	Fraction of nutrients reaching marine end compartment (kg N eq)	
 Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	Impact of toxic substances on freshwater ecosystems
 Land use	Soil quality index, representing the aggregated impact of land use on: Biotic production; Erosion resistance; Mechanical filtration; Groundwater replenishment (Dimensionless – pt)	Transformation and use of land for agriculture, roads, housing, mining or other purposes. The impact can include loss of species, organic matter, soil, filtration capacity, permeability
 Water use	Weighted user deprivation potential (m ³ world eq)	Depletion of available water depending on local water scarcity and water needs for human activities and ecosystem integrity
 Resource use, minerals and metals	Abiotic resource depletion – ADP ultimate reserves (kg Sb eq)	Depletion of non-renewable resources and deprivation for future generations
 Resource use, fossils	Abiotic resource depletion, fossil fuels – ADP-fossil (MJ)	

FIGURE 3.1.4 – Life Cycle Impact Assessment Categories.

© European Commission 2022, Understanding Product Environmental Footprint.

With a growing landscape of environmental evaluation methods for policy making, organisations, and products, a clear and consistent standard dedicated specifically to buildings was still missing. Energy efficiency had been repeatedly identified in UNFCCC, Kyoto, and successive IPCC reports as one of the most effective mitigation pathways, given the large share of CO₂ emissions arising from fossil-fuel-based heating, cooling and electricity use. Buildings, responsible for a major portion of Europe's final energy consumption, offered significant and well-documented opportunities for reduction through measures such as insulation, efficient glazing, thermal-bridge reduction, and high-performance systems. These improvements support national energy security, reduce local pollution, improve indoor comfort, and strengthen competitiveness, an alignment of environmental and socio-economic motivations that increasingly shape EU energy policy. In this context, the European Union developed the Energy Performance of Buildings Directive (**EPBD**) as the cornerstone of its building-sector decarbonization strategy ^[44].

The first version of the directive, issued in 2002, introduced a common methodology for calculating the energy performance of buildings, minimum national performance requirements for new and renovated buildings, mandatory Energy Performance Certificates (EPCs), and periodic inspections of heating and cooling systems. Its definition of energy performance, expressed in kWh/m² per year and based on standardized assumptions about building use, established a common basis for comparison across Member States. EPCs in particular represented a novel market-oriented mechanism; a concise document ranking buildings from A to G, recommending improvement measures, intended to guide buyers and tenants toward more efficient buildings (*figure 3.1.5*). Despite ongoing debate regarding the correlation between EPC ratings and real-estate value, these certificates became a pivotal communication tool and a driver for energy-related renovation decisions ^[44].

A major recast of the EPBD arrived in 2010, strengthening ambition and introducing complementary methodologies. Most notably, the Directive established the cost-optimal calculation framework, enabling Member States to determine minimum energy performance requirements through comparative cost-benefit analyses from both financial and macro-economic perspectives, considering dynamic return rates, taxes, and greenhouse gas emissions costs. It also introduced the concept of the nearly zero-energy building (*nZEB*), requiring public buildings to meet national nZEB standards, thereby anchoring energy performance targets more firmly to long-term climate goals. This recast also triggered a new mandate to develop coherent, suitable standards, with many becoming ISO-driven, thereby forming the technical backbone of harmonized national methodologies across Europe ^[44].

The 2018 revision further aligned the Directive with EU climate and energy targets for 2030 and the Paris Agreement, aiming to accelerate cost-effective renovation and support the transition toward a decarbonized building stock by 2050. This update introduced new mechanisms such as the EU Building Stock Observatory, designed to improve transparency

and allow cross-national comparisons of building performance, and the “Smart Finance for Smart Buildings” initiative, intended to mobilize more than 10 billion euros in public and private investment for deep renovation. Additionally, the revision encouraged the diffusion of electromobility infrastructure, promoted building automation and smart technologies, and laid the groundwork for common European schemes for evaluating the smart readiness of buildings, reflecting a broader shift toward digitalisation and operational performance in real time ^[44].

The most recent recast of the EPBD came in 2024, representing a decisive conceptual shift by extending regulatory attention beyond operational energy toward the full life cycle impacts of buildings. For the first time, the Directive explicitly integrates whole-life carbon considerations, requiring the calculation and disclosure of a building’s global warming potential across construction, operation, and end-of-life stages. This move effectively embeds embodied energy and material-related emissions, often referred to as “grey energy” into the regulatory framework. Under the new provisions, all new buildings will be required to report their lifecycle carbon performance using harmonized methodologies defined at the Union level by 2030. By linking these calculations to Energy Performance Certificates and introducing future limit values for lifecycle emissions, the EPBD reframes building assessment as a combined evaluation of energy demand, carbon intensity, and material impact. In doing so, the Directive consolidates the convergence between policy instruments and analytical frameworks, positioning lifecycle-based evaluation as a central pillar of Europe’s building-sector decarbonization strategy ^[45].

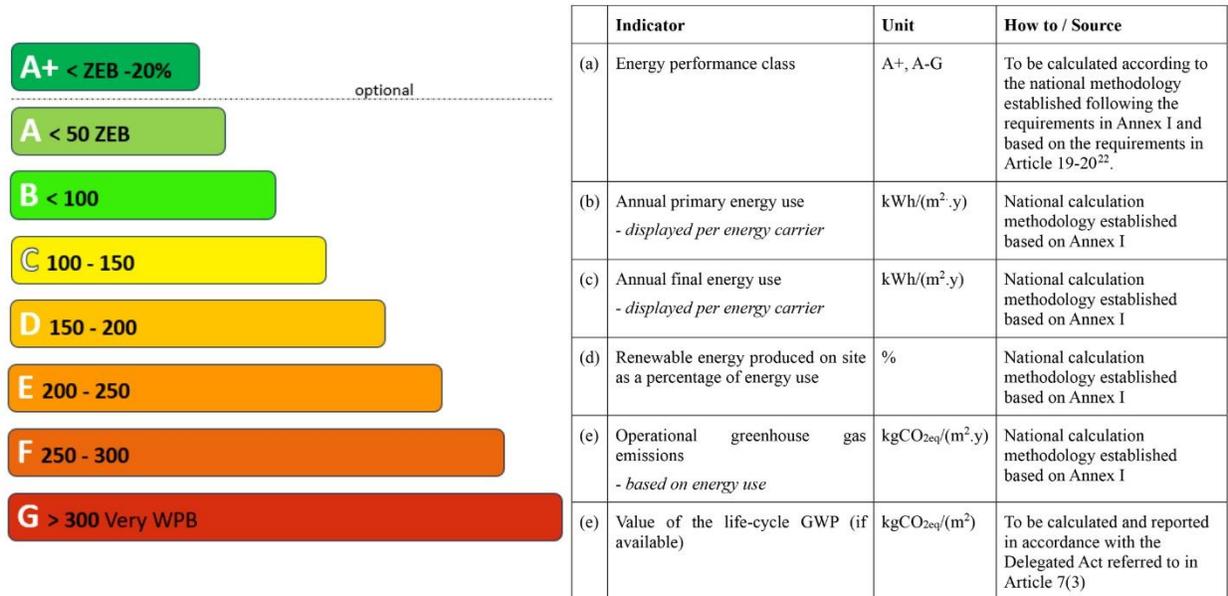


FIGURE 3.1.5 – EPC Performance classes and mandatory indicators.
© European Commission 2024, EPCs and independent control systems.

With the consolidation of energy-performance regulation in Europe, the need for consistent technical methods to support cross-national comparisons became increasingly clear. One of the earliest steps toward this standardization was ISO 13790:2004, which provided a simplified approach to estimating annual energy use for space heating in residential and non-residential buildings. By defining how to calculate heat losses, internal gains, and the annual energy required to maintain set-point temperatures, it offered a reproducible basis for evaluating heating demand at the design stage or in existing buildings. A second, expanded version of the standard arrived in 2008 called Energy Performance of Buildings **(EPB)**, extending the method to cooling needs and introducing hourly schedules for temperature, ventilation, and shading. This shift reflected a broader recognition that building performance depended not only on envelope quality but also on dynamic indoor conditions, occupant behavior, and climatic variability, elements that would later prove fundamental for performance certificates and simulation-based evaluations ^{[46] [47]}.

As energy assessment methods have matured, the earlier ISO 13790 standards have been gradually superseded by a new, more coherent framework designed to enable reliable comparisons across regions, climates, and regulatory systems. This transition culminated in the development of the ISO 52000 family, published in 2017 under a modular structure that defines how the energy performance of buildings should be calculated worldwide. At its core, ISO 52000-1:2017 establishes a holistic methodology to determine a building's overall energy use, whether through measurement or calculation, and to express results in primary energy or other comparable metrics. By defining common boundary conditions, shared physical inputs, consistent zoning principles, and harmonized links to system-specific standards, the EPB framework ensures that different calculation methods, from simplified monthly balances to detailed hourly simulations, remain interoperable. In doing so, it provides a technical backbone that not only supports European EPC schemes but also enables cross-national benchmarking and methodological alignment with a wide spectrum of building-performance frameworks. This modular structure ultimately enables performance assessments to be more transparent, comparable, and adaptable to diverse building traditions and climatic contexts, thereby reinforcing their relevance. ^[48].

As seen in the final conclusions of the 2018 EPBD revision, the European Commission proposed the creation of a Smart Readiness Indicator **(SRI)** as an additional layer of building assessment centred on digital capacity and adaptive operation. Unlike traditional performance indicators that focus on static metrics, the SRI evaluates how well a building can optimise and adjust the functioning of its systems to enhance energy performance and occupant experience. Its methodology is structured around nine technical domains, assessed according to seven desired impacts (*figure 3.1.6*). With this framework, the SRI aims to foster the uptake of advanced technologies such as building automation, digital monitoring, and room-level environmental control, reinforcing the shift toward buildings that operate more intelligently and efficiently in response to real-time conditions and evolving occupant needs ^{[43][49]}.

Although conceived as an optional scheme, the SRI outlines a common European language for assessing technological readiness and is increasingly positioned as a strategic tool for the decarbonisation and digitalisation of the building stock. Member States remain free to test or implement it, yet recent policy developments foresee a gradual move toward wider adoption by 2027, and it will become mandatory for large non-residential buildings with significant HVAC consumption, complemented by reinforced obligations for building automation and control systems. Implementation relies on a shared methodological backbone developed through extensive consultation, while each country defines its own catalogue of smart-ready services and functionality levels. This structure aims to promote transparency and comparability across Europe and to support broader policy mechanisms such as EPCs, renovation passports, and the growing use of digital building twins for real-time simulation and performance feedback [49][50].

At its core, the SRI measures how well a building interacts with its occupants, its internal systems, and the energy grid, addressing functions linked to energy efficiency, comfort, convenience, maintenance, accessibility, and flexibility. The evaluation is based on the functionality level of specific services, where more advanced implementations provide stronger impacts. These impacts are then clustered into three key functional goals optimising energy use, adapting to occupants, and responding to grid signals, each contributing equally to the final score. Despite its potential, the methodology is still new and presents some limitations, such as inconsistencies in the characterization of certain impact criteria and a dependence on expert judgement that makes assessments time-consuming. Nevertheless, the SRI offers a pathway to articulate the added value of smart technologies, supporting the integration of automation, renewable energy systems, data-driven control strategies, and advanced optimisation tools. It also aligns with parallel assessment methods such as LCA, carbon footprint, and green certification schemes, creating opportunities for methodological synergies within a more comprehensive, flexible, and technology-aware performance landscape [50].

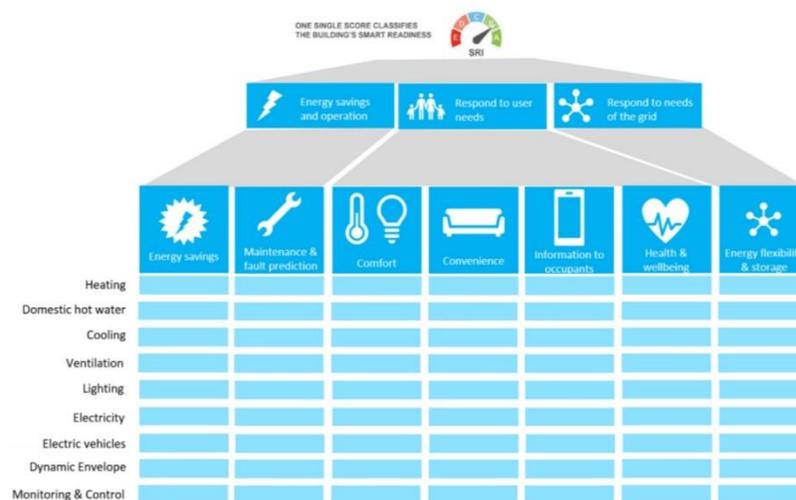


FIGURE 3.1.6 – SRI proposed domains and impacts scheme.

3.2 Architecture Certificates

Meanwhile, from the architectural perspective, the earliest precedent for environmental building assessment emerged in the United Kingdom, where the Building Research Establishment (BRE) traces its institutional origins to 1921, initially founded to raise housing quality and living standards. Throughout the twentieth century, the institution advanced construction science through research on materials, fire safety, seismic analysis, and emerging technologies, gradually consolidating a national reference for building performance. In 1990, these decades of research culminated in the launch of the Building Research Establishment Environmental Assessment Method (**BREEAM**), the first structured tool for environmental assessment of buildings. The original scheme focused on office buildings and operated through a checklist across nine categories (*figure 3.2.1*). Awarding credits for demonstrated best practices and producing five ratings from “Pass” to “Outstanding.” At this early stage, BREEAM prioritized measurable reductions in operational impacts, particularly energy use, reflecting the environmental consciousness raised by the energy crises and Brundtland-era sustainability debates. Over the following decades, the method expanded internationally and across building typologies, evolving from a UK-centric tool into a globally recognized benchmark used across the entire asset lifecycle ^{[21] [51] [53]}.

Today, after nine major revisions, the most recent BREEAM Version 7 of 2024, covers a wide range of project types, based on 6 different technical standards from new residential, new construction, refurbishment, community, infrastructure, and real estate. The contemporary framework also formalizes two certification stages; a “*Design Stage*” certification assessing sustainability strategies before construction, and a “*Post-Construction*” certification verifying the final as-built outcome. This two-step approach enables performance intentions to be embedded early while ensuring that final delivery matches design ambitions, reducing costly retrofits and strengthening quality assurance. Category weightings and minimum standards incorporate whole-life carbon accounting for both operational and embodied emissions, mandatory biodiversity gains, climate-risk analysis, circular-material strategies, inclusivity and social impact criteria, and digital performance forecasting aided by AI ^{[52][53]}.

Applied in more than 80 countries and influencing over 2.5 million registered buildings, BREEAM plays a central role in guiding the built environment toward net-zero pathways, nature-positive outcomes, and ESG-aligned decision-making. In practice, its certification presumes driving carbon reductions in the range of 20–30%, demonstrating concrete influence in improving building performance, reducing operational costs, and aligning development with global sustainability objectives. Its long-standing emphasis on lifecycle thinking, third-party verification, and post-occupancy evaluation has also contributed to the professionalization of sustainability practice, establishing a common vocabulary and methodology for project teams worldwide. In this way, BREEAM has transitioned from a context-specific tool to a global reference framework, shaping contemporary sustainability standards and serving as a precursor to the many certification systems that followed ^[52].

Topic		Topic	
	<ul style="list-style-type: none"> - Integrated design process that optimizes building performance resulting from robust stakeholder engagement - Life cycle costing and service planning to deliver economic sustainability - Considerate, responsible and accountable construction site management practices - Commissioning and handover - Post-handover aftercare including post-occupancy evaluation and zero carbon transition planning 		<ul style="list-style-type: none"> - Energy and carbon performance of building envelope, services and fittings - Predicted operational energy and carbon performance - Energy use monitoring of systems and occupiers - Low carbon design measures including on-site or near-site low and zero carbon energy generation technologies - Energy efficient equipment selection and procurement - Energy efficient system selection and procurement - Flexible demand response - Installation of controls for HVAC systems
	<ul style="list-style-type: none"> - Natural light to support visual performance, comfort and well-being - Appropriate design and controls of artificial light - Circadian rhythm - Indoor air quality - Thermal comfort - Acoustic performance - Safe and accessible design, providing safe access to the asset and outdoor space/access to nature beyond private space - Private space (residential only) - Natural hazard risk management - Water quality 		<ul style="list-style-type: none"> - Transport assessment and travel plan - Sustainable transport measures such as EV charging infrastructure, active travel support for cyclists, all supported by the outcome from the travel plan
	<ul style="list-style-type: none"> - Building life cycle assessment with embodied carbon reporting requirements including MEP services. - Environmental product declarations for critical building components - Responsible sourcing of construction products - Durability and resilience - Material efficiency 		<ul style="list-style-type: none"> - Water efficiency of water-consuming fixtures and expected use of recycled water from approved blackwater, greywater and rainwater systems. - Water use monitoring of systems and occupiers - Water leak detection and prevention - Water efficient equipment and systems to ensure resilience to water stress - Predicted operational water consumption to ensure resilience to water stress
	<ul style="list-style-type: none"> - Construction waste management - Recycled aggregates - Operational waste planning - Speculative finishes - Adapting to climate change - Disassembly and adaptability 		<ul style="list-style-type: none"> - Site selection - Ecological risks and opportunities - Managing impacts on ecology - Ecological change and enhancement, specifically supporting Biodiversity Net Gain and wider site sustainability including reducing heat island effect. - Long term ecological management
			<ul style="list-style-type: none"> - Impact of refrigerants - Local air quality - Flood and surface water management - Reduction of nighttime light pollution - Reduction of noise pollution

FIGURE 3.2.1 – BREEAM Category Indicators.
 © BREEAM 2024, New Construction V7 Technical Summary [53].

Subsequently, in the United States, the first ideas of standardizing building performance began to take shape from professional discussions in the 1980s, eventually formalizing in 1993 with the creation of the U.S. Green Building Council (USGBC). The new nonprofit held its first conference that year in Chicago, setting as its primary objective the development of a national sustainability rating system. In collaboration with the American Society of Testing and Materials, and after a careful review of existing models, such as BREEAM, the Canadian BEPAC framework, and the Green Building Challenge, they presented in 1995 an independent evaluation system called Leadership in Energy and Environmental Design (LEED), with a deeper focus on energy impacts [21].

Over the following years, LEED expanded based on the retrofit of first attempts, culminating with the release of the first official version 1.0 in 1998, based on a system of 40 performance-based credits, revealing some limitations but gaining enough traction to start with a constant upgrading process. Today, version 5.0, LEED's latest version, was launched in 2025, reflecting advancements in building science and a deeper understanding of environmental and human-health impacts, placing particular emphasis on three overarching impact areas:

decarbonization, quality of life, and ecological conservation and restoration. This version reinforces performance-based pathways, integrates resilience principles, and encourages responsible and safe resource use, aligning the system with contemporary visions of a near-zero-carbon future [54].

LEED has evolved in scope and complexity, today expanding into a set of rating systems applicable to six main project typologies: Building Design and Construction, Interior Design and Construction, Building Operations and Maintenance, Neighborhood Development, Residential, and Cities. Certification is awarded according to a credit-based scoring system organized across multiple thematic categories (figure 3.2.2), with projects required to meet the Minimum Program Requirements and all mandatory prerequisites, and then summing optional credits to accomplish a score equivalent to 1 of the 4 final grades from “Certified” to “Platinum”. The online credit library tool provides detailed guidance on goals, metrics, and methodologies for assessing each credit, enabling teams to tailor certification pathways to the project’s context, site conditions, and social, environmental, and financial objectives [54].

Today, LEED stands among the most influential sustainability certification systems globally, informing both public and private sector development. It is used in more than 180 countries, with more than 100,000 certified commercial projects. Its influence extends beyond certification by shaping policy, guiding investment, and fostering industry expectations regarding energy performance, indoor environmental quality, and long-term operational savings. Buildings that achieve LEED certification typically demonstrate significant reductions in operational energy use, alongside improvements in occupant well-being and resource efficiency. Through this sustained evolution, LEED has grown from a national initiative into a global benchmark that continues to define and advance sustainable architectural practice [54].

<p>Integrative Process, Planning and Assessments (IP)</p> <p>IPp1 Climate Resilience Assessment</p> <p>IPp2 Human Impact Assessment</p> <p>IPp3 Carbon Assessment</p> <p>IPc1 Integrative Design Process</p>	<p>Water Efficiency (WE)</p> <p>WEp1 Water Metering and Reporting</p> <p>WEp2 Minimum Water Efficiency</p> <p>WEc1 Water Metering and Leak Detection</p> <p>WEc2 Enhanced Water Efficiency</p>	<p>Materials and Resources (MR)</p> <p>MRp1 Planning for Zero Waste Operations</p> <p>MRp2 Quantify and Assess Embodied Carbon</p> <p>MRC1 Building and Materials Reuse</p> <p>MRC2 Reduce Embodied Carbon</p> <p>MRC3 Low-Emitting Materials</p> <p>MRC4 Building Product Selection and Procurement</p> <p>MRC5 Construction and Demolition Waste Diversion</p>
<p>Location and Transportation (LT)</p> <p>LTc1 Sensitive Land Protection</p> <p>LTc2 Equitable Development</p> <p>LTc3 Compact and Connected Development</p> <p>LTc4 Transportation Demand Management</p> <p>LTc5 Electric Vehicles</p>	<p>Energy and Atmosphere (EA)</p> <p>EAp1 Operational Carbon Projection and Decarbonization Plan</p> <p>EAp2 Minimum Energy Efficiency</p> <p>EAp3 Fundamental Commissioning</p> <p>EAp4 Energy Metering and Reporting</p> <p>EAp5 Fundamental Refrigerant Management</p> <p>EAc1 Electrification</p> <p>EAc2 Reduce Peak Thermal Loads</p> <p>EAc3 Enhanced Energy Efficiency</p> <p>EAc4 Renewable Energy</p> <p>EAc5 Enhanced Commissioning</p> <p>EAc6 Grid Interactive</p> <p>EAc7 Enhanced Refrigerant Management</p>	<p>Indoor Environmental Quality (EQ)</p> <p>EQp1 Construction Management</p> <p>EQp2 Fundamental Air Quality</p> <p>EQp3 No Smoking or Vehicle Idling</p> <p>EQc1 Enhanced Air Quality</p> <p>EQc2 Occupant Experience</p> <p>EQc3 Accessibility and Inclusion</p> <p>EQc4 Resilient Spaces</p> <p>EQc5 Air Quality Testing and Monitoring</p>
<p>Sustainable Sites (SS)</p> <p>SSp1 Minimize Site Disturbance</p> <p>SSc1 Biodiverse Habitat</p> <p>SSc2 Accessible Outdoor Space</p> <p>SSc3 Rainwater Management</p> <p>SSc4 Enhanced Resilient Site Design</p> <p>SSc5 Heat Island Reduction</p> <p>SSc6 Light Pollution Reduction</p>		<p>Project Priorities (PR)</p> <p>PRc1 Project Priorities</p> <p>Project Priority 1: <i>Insert credit name</i></p>

FIGURE 3.2.2 – LEED Category Indicators.

© LEED 2025, New Building Design and Construction (project scorecard) [54].

Alternative efforts to assess sustainable performance in buildings took place in Germany and led in 1996 to the foundation of the Passivhaus Institut (**PHI**). Based on early research by Wolfgang Feist and an interdisciplinary team of physicists, PHI consolidated the lessons of several experimental projects, demonstrating that extremely low energy consumption was technically feasible even in central-European climates, opening the path toward a performance-based standard focused on reducing the need for active heating through rigorous design rather than add-on technologies ^[55].

In contrast to credit-based certification systems, Passivhaus operates as a strict performance standard, applicable to buildings and building components, and grounded in quantifiable thresholds for heating and cooling demand, airtightness, and renewable primary energy use (*figure 3.2.3*). The standard relies on five core design principles; high-performance windows, balanced mechanical ventilation with heat recovery, robust thermal insulation, airtightness, and thermal-bridge reduction, applied according to local climatic conditions. Over time, PHI expanded its scope to three types of certifications, *Passive House* for new buildings, *EnerPHit* for refurbishments, and the *PHI Low Energy Building Standard* for projects that cannot meet full criteria but still benefit from many advantages of the approach. Each of these can be achieved at “Classic”, “Plus”, or “Premium” levels, depending on renewable energy generation and primary energy demand ^{[55][56]}.

PHI has gradually grown into a broad international network, supported by national branches and the International Passive House Association (*iPHA*), while maintaining the original institute as the technical and scientific core of the standard. Beyond certification, PHI plays a leading role in research, component testing, professional training, and software development. Its principal calculation tool, the Passive House Planning Package (*PHPP*), has evolved over more than two decades, now offering dynamic simulations, climate-adjusted benchmarks, stress tests for summer comfort, interfaces for data monitoring, component libraries, and expanded workflows for complex building typologies. PHPP 10, released in 2021, added improved climate datasets, support for southern-hemisphere orientation, enhanced plausibility checks, and new modules for heat pumps, multifamily energy modelling, and building-component performance evaluation, while integrating digital distribution and compatibility with the Passive House Database. ^{[55][56]}.

Today, Passivhaus is recognized worldwide as one of the most rigorous building energy standards, with thousands of certified buildings and increasingly adapting the criteria to different environmental conditions. Research consistently shows that Passivhaus buildings achieve 70–90% reductions in heating demand relative to conventional construction, while providing stable indoor comfort, high air quality, and long-term operational savings. Through this combination of measurable performance, clear thresholds, and robust design methods, Passivhaus stands as a distinct and influential approach within the landscape of sustainable building assessment, complementing broader frameworks by providing an uncompromising benchmark for energy efficiency ^[55].

				Criteria ¹			Alternative Criteria ²
Heating							
Heating demand	[kWh/(m ² a)]	≤	15			-	
Heating load ³	[W/m ²]	≤	-			10	
Cooling							
Cooling + dehumidification demand	[kWh/(m ² a)]	≤	15 + variable allowance ⁴				
Airtightness							
Pressurization test result n ₅₀	[1/h]	≤	0.6				
Renewable Primary Energy (PER)⁵				Classic	Plus	Premium	
PER demand ⁶	[kWh/(m ² a)]	≤	60	45	30	±15 kWh/(m ² a) deviation from criteria... ...with compensation of the above deviation by different amount of generation ⁸	
Renewable energy generation ⁷ (with reference to projected building footprint)	[kWh/(m ² a)]	≥	-	60	120		

FIGURE 3.2.3 – PHI Criteria Indicators.

© PHI 2023, *Criteria for Buildings* [56].

In 2006, under the combined efforts of the U.S. Green Building Council and the Canada Green Building Council to support regional independence in the Pacific Northwest, architects Jason F. McLennan and Bob Berkebile proposed a new sustainability program rooted in the ideas first articulated in their book *The Living Building*. The resulting Living Building Challenge (**LBC**) was conceived not simply as another rating tool but as a shift in worldview, a philosophy first, an advocacy instrument second, and only then a certification framework. Its ambition extended far beyond improving building efficiency, it aimed to reconnect occupants with light, air, food, nature, and community to create buildings that operate self-sufficiently within the resource limits of their site and to ensure positive ecological and social impacts rather than simply reducing harm. The initiative was grounded in a profound cultural shift from minimizing damage to co-creating regenerative futures, and in 2011 its administration moved to the newly formed non-profit International Living Future Institute (*ILFI*), which expanded the program into a broader family including the Living Community Challenge, Living Product Challenge, Zero energy certification, Zero carbon certification, Affordable Housing Initiative, and Biophilic Design Initiative [57].

Distinctively from other certification frameworks that are built around modeled scenarios or prescriptive measures, the LBC is grounded in actual performance, requiring each project to verify its results over twelve consecutive months of operation. Its structure is organized into seven performance categories, or “*Petals*” expanded to 20 Indicators or “*Profound Imperatives*” that articulate the program’s aspirations (figure 3.2.4). These Imperatives form the basis of three certification pathways; *Core Certification*, where at least 10 core imperatives are achieved, *Petal Certification* where on top of the basic 10 imperatives there is a specific category that accomplishes a deeper score, and *Living Certification* which requires achieving all Imperatives assigned to the project’s typology. Applicability across new construction, renovation, interiors, and landscape projects is expanded through regional equivalencies, ensuring climate, material availability, and cultural context shape the project’s solution [57] [58].

The latest version, LBC 4.1 (2025), reflects more than a decade of iterative refinement through third-party audits, technical advisory groups, and lessons emerging from design teams, owners, and occupants themselves. It strengthens requirements for biodiversity, social equity, food and mobility systems, and soil health, thereby progressively aligning the standard with emerging knowledge on resilient design. Despite its demanding character, the LBC has steadily grown into one of the most ambitious global frameworks for regenerative architecture*. According to ILFI’s latest public reports, there are over 900 registered projects in more than 30 countries, and more than 120 completed certifications across Core, Petal, and Living levels, representing a rapidly growing portfolio despite its demanding requirements. Independent reviews confirm that LBC projects often achieve net-positive energy, deep material transparency, and record-low operational emissions, demonstrating levels of performance that frequently exceed national standards by large margins. In this way, the Living Building Challenge has evolved into both a technical benchmark and a cultural manifesto functioning as a “Trojan horse” that satisfies performance thresholds while quietly embedding a holistic ethic of ecological restoration, social justice, and design excellence into contemporary architectural practice. [57] [58].

SUMMARY MATRIX

The Living Building Challenge is composed of 20 Imperatives grouped into seven Petals. Some Imperatives are not required for all Typologies.

PETAL		IMPERATIVE	TYPOLOGY			
			New Building	Building Renovation	Interior	Landscape + Infrastructure
PLACE	01 Ecology of Place	Core Imperative	Required	Required	Not Required	Required
	02 Urban Agriculture	Scale Jumping Allowed	Required	Required	Not Required	Not Required
	03 Habitat Exchange	Scale Jumping Allowed	Required	Required	Not Required	Required
	04 Human Scaled Living	Scale Jumping Allowed	Required	Required	Required	Not Required
WATER	05 Responsible Water Use	Handprinting Imperative	Required	Required	Required	Required
	06 Net Positive Water	Handprinting Imperative	Required	Required	Required	Required
ENERGY	07 Energy + Carbon Reduction	Core Imperative	Required	Required	Required	Required
	08 Net Positive Carbon	Core Imperative	Required	Required	Required	Required
HEALTH + HAPPINESS	09 Healthy Interior Environment	Core Imperative	Required	Required	Required	Not Required
	10 Healthy Interior Performance	Core Imperative	Required	Required	Required	Not Required
	11 Access to Nature	Core Imperative	Required	Required	Required	Not Required
MATERIALS	12 Responsible Materials	Core Imperative	Required	Required	Required	Required
	13 Red List	Core Imperative	Required	Required	Required	Required
	14 Responsible Sourcing	Core Imperative	Required	Required	Required	Required
	15 Living Economy Sourcing	Core Imperative	Required	Required	Required	Required
	16 Net Positive Waste	Core Imperative	Required	Required	Required	Required
EQUITY	17 Universal Access	Core Imperative	Required	Required	Required	Required
	18 Inclusion	Core Imperative	Required	Required	Required	Required
BEAUTY	19 Beauty + Biophilia	Core Imperative	Required	Required	Required	Required
	20 Education + Inspiration	Core Imperative	Required	Required	Required	Required

FIGURE 3.2.4 – LBC Criteria Indicators.

© International Living Future Institute 2024, Program Manual [58].

* regenerative architecture; an approach that seeks not only to minimise harm but to actively restore and generate net-positive impacts.

A further shift in sustainability assessment occurred when attention turned toward the health of occupants, a dimension long acknowledged but rarely formalized as a performance criterion. In response to this approach, the **WELL** Building Standard was launched in 2014 by Delos Living, introducing a new framework centred on scientific evidence on how buildings influence physical, mental, and social well-being. Drawing on environmental health literature, epidemiology, ergonomics, building science, and public health standards, WELL positions building design and management as active determinants of human health rather than passive background conditions. Unlike earlier tools that treated health as an auxiliary benefit of energy or environmental strategies, WELL placed well-being as the primary design driver, verified through on-site performance tests conducted by independent assessors ^[59].

After several years of pilot testing, iterative refinements, and wide stakeholder feedback, the second major version, WELL v2, was finalized and released in 2020. It consolidated earlier variations into a single, globally applicable system designed to be more adaptable, resilient, and transparent. WELL v2 organizes its criteria into ten concepts (*figure 3.2.5*), each structured around mandatory “preconditions” and optional “optimizations” adding up to a maximum of 110 points. Unlike other systems, WELL is based on a weighting logic, where features are scored according to the scale of their impact on the building population, acknowledging that some interventions, such as air quality or daylighting, must apply universally across the building, while others may be relevant only to specific user groups or zones. WELL also distinguishes two certification pathways; “*WELL Certification*” for predominantly owner-occupied projects and “*WELL Core*” for multi-tenant buildings, each with differentiated applicability criteria. The framework is ultimately performance-based, requiring in-situ measurement of air, water, light, sound, and thermal conditions by accredited WELL Performance Testing Agents and, with 5 final scores from *Bronze* to *Platinum* based on the points sum ^{[59] [60]}.

Over the past decade, WELL has expanded into a global benchmark for health-centred design. Its development reflects a rigorous standard-setting process, which underwent hundreds of public comments, periodic updates, and formal validation by an international Governance Council that evaluated each feature against four main drivers: evidence-based, verifiable, implementable, and externally reviewed. As of 2024, WELL reports thousands of certified and registered projects across all major regions, with portfolios representing corporate offices, schools, residential developments, hospitals, and public buildings. The system’s rapid uptake aligns with a broader shift in ESG agendas, where health performance has become tied to productivity, employee retention, and risk-mitigation strategies. Today, WELL serves not only as a certification but also as a reference model that informs organizational policies, portfolio-level benchmarking, and health-oriented governance across the built environment ^{[59] [60]}.



FIGURE 3.2.5 – WELL Indicators.

© International WELL Building Institute, Digital Platform.

As the next decade began, a new wave of sustainability frameworks emerged, building on the retrofitting and addressing the gaps left by pioneering certification systems. This was particularly evident to specialists at the International Finance Corporation (IFC), who noticed that existing tools were often too complex, costly, or inaccessible for the markets where sustainable development was most urgently needed. In response, IFC developed an alternative framework called Excellence in Design for Greater Efficiencies (**EDGE**), officially launched in 2015 with the intention of offering a simpler, low-cost, and more inclusive pathway to green building performance. Unlike other frameworks designed primarily for high-end developments, EDGE was conceived to deliver practical value for low-income communities and emerging economies. Its simplicity is grounded on an online tool that can be easily used for several building typologies based on localized data to deliver concrete results on the costs, savings, and payback of green solutions, information that became especially valuable for banks and investors seeking key metrics to unlock green investments and loans ^[61].

Over time, EDGE evolved from a diagnostic tool into a certification system supported by partnerships with international verifiers and green building councils across the Global South. The methodology remains intentionally streamlined, organized around indicators grouped on three core categories Energy, Water, and Materials (*figure 3.2.6*), and applicable to more than a dozen building typologies, from homes, hotels, healthcare facilities, schools, offices, and industrial buildings. The current Version 3.1, adopted in 2025, consolidates the system into three certification levels; “*EDGE Certified*” for projects that accomplished a minimum 20% savings across the three categories, “*EDGE Advanced*” for at least 40% savings in comparison to a typical similar building, and “*EDGE Zero Carbon*” awarded to buildings demonstrating operational carbon neutrality for energy for at least one year of use. Supported through an entirely digital submission and auditing process, the system provides accessible pathways encouraging developers to quantify environmental performance while maintaining a strong financial lens. This combination has simplified verification positioning EDGE as a powerful accelerator for sustainable construction in emerging markets ^[62].

A decade after its introduction, EDGE has evolved into a global movement demonstrating that sustainable construction is both feasible and financially advantageous in emerging markets. The system has helped unlock concessional loans and green financing instruments, particularly in regions such as Africa or Latin America, where EDGE-certified buildings have shown stronger market performance. IFC has also built an extensive professional network that supports adoption in more than 80 countries. Thousands of projects are now registered worldwide, collectively contributing to reduced operational energy demand, lower embodied carbon, and measurable utility savings. In this way, EDGE complements the broader landscape of assessment frameworks by prioritizing clear metrics, financial accessibility, and tangible benefits, bridging sustainability ambitions with real market transformation ^[61].

Energy Efficiency Measures

Choose energy efficiency measures to achieve savings of at least 20%.

- EEM01* Window-to-Wall Ratio: 8%
- EEM02 Reflective Roof: Solar Reflectance Index 85
- EEM03 Reflective Exterior Walls: Solar Reflectance Index 85
- EEM04 External Shading Devices: Annual Average Shading Factor (AASF) 0.27
- EEM05* Insulation of Roof: U-value 0.19 W/m²-K
- EEM06* Insulation of Ground/Raised Floor Slab: U-Value 0.35 W/m²-K
- EEM07 Green Roof
- EEM08* Insulation of Exterior Walls: U-Value 0.45 W/m²-K
- EEM09* Efficiency of Glass: U-Value 1.95 W/m²-K, SHGC 0.49 and VT 0.45
- EEM10 Air Infiltration of Envelope: 50% Reduction
- EEM11 Natural Ventilation
- EEM12 Ceiling Fans
- EEM13* Cooling System Efficiency: 3.7 COP (W/W)
- EEM14 Variable Speed Drives
- EEM15 Fresh Air Pre-conditioning System: Efficiency 65%
- EEM16* Space Heating System Efficiency: 92.58%
- EEM17 Room Heating Controls with Thermostatic Valves
- EEM18* Domestic Hot Water (DHW) System : Solar 50%, Heat Pump 50%, Boiler 0%, Instantaneous Water Heater 0%, District Hot Water Sys...
- EEM19 Domestic Hot Water Preheating System
- EEM20 Economizers
- EEM21 Demand Control Ventilation Using CO₂ Sensors
- EEM22* Efficient Lighting for Internal Areas
- EEM23 Efficient Lighting for External Areas
- EEM24 Lighting Controls
- EEM25 Skylights
- EEM26 Demand Control Ventilation for Parking Using CO₂ Sensors
- EEM27 Insulation for Cold Storage Envelope
- EEM28 Efficient Refrigeration for Cold Storage
- EEM29 Efficient Refrigerators and Clothes Washing Machines
- EEM30 Submeters for Heating and/or Cooling Systems
- EEM31 Smart Meters for Energy
- EEM32 Power Factor Corrections
- EEM33 Onsite Renewable Energy: 25% of Annual Energy Use
- EEM34 Other Energy Saving Measures

Materials Efficiency Measures

Choose building material options to achieve savings of at least 20%, indicating thickness.

MEM01* Bottom Floor Construction

Base Case Material: Concrete Slab | In-situ Reinforced Conventional Slab
Thickness : 100mm & Steel : 35kg/m²
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Steel Rebar (kg/m²):

U-Value (W/m²-K): Embodied Carbon (kg/m²):

MEM02* Intermediate Floor Construction

Base Case Material: Concrete Slab | In-situ Reinforced Conventional Slab
Thickness : 200mm & Steel : 33kg/m²
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Steel Rebar (kg/m²): Embodied Carbon (kg/m²):

MEM03* Floor Finish

Base Case Material: Tiled | Ceramic Tiles
Thickness : 10mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Embodied Carbon (kg/m²):

MEM04* Roof Construction

Base Case Material: Concrete Slab | In-situ Reinforced Conventional Slab
Thickness : 200mm & Steel : 35kg/m²
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Steel Rebar (kg/m²):

U-Value (W/m²-K): Embodied Carbon (kg/m²):

MEM05* Exterior Walls

Base Case Material: Brick Wall | Solid brick (0-25% voids) with external and internal plaster
Thickness : 230mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): U-Value (W/m²-K): Embodied Carbon (kg/m²):

MEM06* Interior Walls

Base Case Material: Brick Wall | Solid brick (0-25% voids) with external and internal plaster
Thickness : 124mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Embodied Carbon (kg/m²):

MEM07* Window Frames

Base Case Material: Steel
Type 1

Default Base Case Material

Proportion %: Embodied Carbon (kg/m²):

MEM08* Window Glazing

Base Case Material: Single Glazing
Thickness : 6mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): U-Value (W/m²-K): Embodied Carbon (kg/m²):

MEM09* Roof Insulation

Base Case Material: X - No Insulation
Thickness : 0mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Embodied Carbon (kg/m²):

MEM10* Wall Insulation

Base Case Material: X - No Insulation
Thickness : 0mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Embodied Carbon (kg/m²):

MEM11* Floor Insulation

Base Case Material: Polystyrene Foam Spray or Board Insulation
Thickness : 47.6mm
Type 1

Default Base Case Material

Proportion %: Thickness (mm): Embodied Carbon (kg/m²):

Water Efficiency Measures

Choose water efficiency measures to achieve savings of at least 20%.

- WEM01* Water-efficient Showerheads: 6 L/min
- WEM02* Water-efficient Faucets for all Bathrooms: 2 L/min
- WEM04* Efficient Water Closets for All Bathrooms: 6 L/High volume flush and 3 L/Low volume flush
- WEM06 Water-efficient Bidet: 2 L/min
- WEM07 Water-efficient Urinals: 2 L/flush
- WEM08* Water-efficient Faucets for Kitchen Sinks: 8 L/min
- WEM09 Water-efficient Dishwashers: 17 L/Cycle
- WEM10 Water-efficient Pre-rinse Spray Valves for Kitchen: 2 L/min
- WEM11 Water-efficient Washing Machines: 35 L/Cycle
- WEM12 Swimming Pool Covers: 30% Area Covered
- WEM13 Water-efficient Landscape Irrigation System: 4 L/m²/day
- WEM14 Rainwater Harvesting System: 300 m³ of Catchment Area
- WEM15 Waste Water Treatment and Recycling System: 100% Treated
- WEM16 Condensate Water Recovery: 100% Recovery
- WEM17 Smart Meters for Water

FIGURE 3.2.6 – EDGE Home Indicators.
© International Finance Corporation, EDGE App.

While most of the frameworks reviewed in this chapter operate at a global scale, several others have emerged with a more national scope, responding to local regulatory needs and territorial priorities. In Italy, this role has been taken by **ITACA**, the *Institute for Innovation and Transparency of Procurement and Environmental Compatibility*, whose origins trace back to the late 1990s, but was formally consolidated in 2005 as a non-profit association created by the Italian *Conference of Regions*. From the beginning, its mission extended well beyond certification, positioning itself as a coordinating body to support public administration, foster shared guidelines among regions, and promote research and training related to sustainability. Through this institutional platform, ITACA became a space for dialogue between diverse experts, national authorities, and stakeholders, shaping tools and procedures that could influence socio-economic and environmental development across the country ^[63].

The ITACA environmental assessment protocol derives from *SBTool*, a flexible international comparative methodology developed within the Green Building Challenge, and was adapted to Italian conditions as the standard UNI PdR 13, with the last update in 2019. The protocol evaluates a building's overall level of environmental quality by examining not only its energy performance but also its broader impacts on resources, environmental loads, indoor wellbeing, and long-term life-cycle effects. Its structure is organized into five main areas, site quality, resource consumption, environmental loads, indoor environmental quality, and service quality, each articulated into categories and criteria assessed through a self-evaluation spreadsheet (*figure 3.2.7*). Scores range from -1 for projects below current good practice to +5, representing progressively higher sustainability performance. The methodology is used for a wide variety of building types; residential, office, commercial, and industrial, becoming an operational tool for designers, public authorities, and clients looking for added value. It is also recognized as the reference system for the national construction inspection regime, supported by training programs and a national register of certified experts and inspectors ^{[63] [64]}.

Today, ITACA stands as one of the most widely adopted national sustainability tools in Italy, integrated into regional laws, urban plans, public interventions, and, in some cases, as minimum environmental criteria, where numerous local regulations aim to encourage sustainable building practices. Its dissemination has resulted in thousands of assessed and certified buildings, the establishment of regional protocols for both residential and non-residential sectors, and the development of related initiatives such as the emerging urban-scale ITACA protocol. As a result, ITACA contributes to harmonizing sustainability practices across the country while maintaining the flexibility needed to account for local climatic and regulatory contexts. Its evolution reflects Italy's efforts to align design practice, public procurement, and environmental policy within a shared, measurable framework, thereby consolidating its position as one of the most influential national systems ^{[63] [64]}.

LIST OF CRITERIA AND RELATED WEIGHTS AND SCORES

LIST OF CRITERIA	
A	Site development and regeneration
A.1	Site selection
X A.1.1	Ecological value of soil
X A.1.2	Accessibility to public transport
X A.1.3	Proximity to infrastructure
X A.1.4	Proximity to services
A.2	Site development
A.2.1	Use of native or naturalized plant species
A.2.2	Equipped outdoor areas for common use
A.2.3	Support for the use of bicycles
A.2.4	e-Mobility
B	Energy and resource consumption
B.1	Primary energy required during the life cycle
X B.1.1	Total primary energy
X B.1.7	Global non-renewable primary energy
B.2	Energy from renewable sources
X B.2.2	Renewable energy for thermal uses
X B.2.3	Energy produced on site for electrical uses
B.3	Materials
X B.3.3	Renewable materials
X B.3.4	Recycled materials
X B.3.5	Local materials
X B.3.6	Disassembly of the building
B.3.7	Adaptability for future uses
X B.3.8	Certified materials
B.4	Waterfall
X B.4.3	Indoor water consumption
B.4.4	Water consumption for irrigation
B.6	Envelope performance
X B.6.1	Thermal energy useful for heating
X B.6.2	Thermal energy useful for cooling
X B.6.3	Average global heat transfer coefficient
X B.6.4	Solar radiation control
C	Environmental loads
C.1	Greenhouse gas emissions
X C.1.2	Greenhouse gas emissions during operation
C.3	Solid waste
C.3.3	Land reuse
D	Indoor environmental quality
D.1	Air quality and ventilation
D.1.5	Radon
X D.1.8	Ventilation
D.2	Thermal comfort
D.2.5	Operating temperature in the summer period
D.3	Visual comfort
X D.3.2	Sufficient natural light
D.4	Acoustic comfort
D.4.6	Internal acoustic quality
X D.4.7	Acoustic quality of the building
D.5	Electromagnetic pollution
X D.5.1	Minimizing exposure to ELF magnetic fields
E	Quality of service
E.1	Controllability
X E.1.1	Efficiency of control systems
E.2	Optimizing performance during the operational phase
X E.2.1	Availability of technical documentation of buildings
E.2.2	Consumption monitoring
E.3	Services for users
E.3.1	Functional space equipment
E.4	Social aspects
E.4.1	Universal access to the site and building
H	Adaptation to climate change
H.1	Temperature increase
X H.1.1	Albedo of surfaces
H.2	Extreme rainfall
H.2.1	Soil permeability

FIGURE 3.2.7 – ITACA Residential Indicators.

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Another exemplary case of nationally grounded efforts to develop tailored sustainability frameworks is the Belgian **GRO** tool, introduced in its first consolidated form in 2018 and strongly driven by public authorities. Initially developed under the impulse of the Flemish Government, GRO progressively evolved into an interregional instrument adopted across Flanders, Wallonia, and the Brussels-Capital Region. The name “GRO” alludes to the name of the Norwegian Prime Minister Gro Harlem Brundtland, who authored the report of *Our Common Future*. Conceived not as a market-driven label but as a public, freely accessible assessment instrument, GRO aims to help public clients and design teams translate abstract sustainability ambitions into concrete, project-specific decisions. Its integrated vision addresses environmental performance, health, circularity, and long-term resilience, positioning GRO closer to a design support and governance framework than to a conventional certification scheme ^[65].

Distinctively from rating systems focused on final compliance, GRO is structured as a process-oriented tool that accompanies projects throughout their lifecycle. Sustainability is framed as a trajectory rather than a one-off outcome. The methodology is organized into three analytical levels aligned with project phases: *Level 0* Context Analysis, *Level 1* Concept, and *Level 2* Design & Evaluation. The process begins with an assessment of site-specific opportunities and constraints to ensure compatibility between the intended program and its territorial, environmental, and climatic context. Based on this analysis, ambition levels are collaboratively defined with the design team, thereby guiding the development of a holistic concept supported by operational guidelines. Throughout design and execution, sustainability choices are continuously monitored and verified against predefined criteria, reinforcing GRO’s role as a shared framework for communication, cooperation, and decision-making among stakeholders ^{[65][66]}.

Performance is assessed across eight core thematic domains, including climate-responsive design, energy, health, circularity, water, environmental impact, social qualities, and management, each translated into measurable criteria (*figure 3.2.8*). Rather than ranking projects competitively, GRO evaluates performance qualitatively through three levels from *good*, *better*, and *excellent*, with results visualized through a final radar chart that highlights strengths and areas for improvement. Equal weighting across themes emphasizes balance and coherence over score optimization. As of the interregional GRO 2025.1 version, the tool is applicable to new construction and renovation projects of any scale or function, public or private, and is supported by an extensive set of open-access manuals and calculation files. GRO has thus become the Belgian public reference for sustainable building assessment, demonstrating how policy-driven, non-commercial frameworks can effectively steer design quality, climate resilience, and circular thinking within the construction sector ^{[65][66]}.

LEVEL 1 CONCEPT		LEVEL 2 DESIGN	
CRD	Climate Responsive Design	 CRD 1 - Air	
		 CRD 2 - Heat	
		 CRD 3 - Coolness	
		 CRD 4 - Daylight	
ENE	Energy	 ENE 1 - Primary energy consumption excl. PV	
		 ENE 2 - PV generation	
HEA	Healthy building	 HEA 1 - Visual comfort	
		 HEA 2 - Acoustic comfort	
		 HEA 3 - Healthy indoor climate	
		 HEA 4 - User Influence	
SOC	Social and functional qualities	 SOC 1 - Socially Safe Design	
		 SOC 2 - Facilitating sustainable and safe mobility	
		 SOC 3 - Integrated Accessibility	
CIRC	Circular construction	 CIRC 1 - Recovery	
		 CIRC 2 - Spatial reversibility	
		 CIRC 3 - Technical reversibility	
		 CIRC 4 - Life Cycle Analysis	
LCC	Manage and maintenance	 LCC 1 - Maintenance-friendly design	
		 LCC 2 - Cleaning-conscious design	
		 LCC 3 - Smart technologies	
ECO	Environment	 ECO 1 - Biodiversity	
		 ECO 2 - Impact on the environment	
		 ECO 3 - Sustainable site management	
WAT	Water	 WHAT 1 - Integrated water management	
		 WHAT 2 - Reuse of rainwater	
		 WHAT 3 - Water consumption	

FIGURE 3.2.8 – GRO Criteria Indicators.
 © GRO-tool, BY-NC-ND-4.0 2025.1 [66].

3.3 Categorization

With a clearer understanding of sustainable architecture constructed through the previous chapters, the initial definition stated in the late 1980s has been progressively expanded and refined. What began on a theoretical basis, across a complex constellation of visions over the past decades, has been translated into increasingly operational frameworks that guide the practice of design. This evolution reflects a shift from an abstract field toward applied methodologies capable of responding to the environmental pressures generated by economic growth, urban expansion, and continuous industrialization. As environmental awareness intensified during the late twentieth century, academic and professional discourse has focused on identifying environmental problems and developing tools to mitigate the impacts of industrial activity. Since then, a growing number of assessment methods, standards, and directives emerged with the aim of measuring, benchmarking, and improving environmental “performance” across different sectors. In the building industry, these efforts resulted in a proliferation of building environmental assessment methods, many of which gained wide adoption, institutional recognition, and standardization ^[67] ^[68].

However, while these tools have proven effective in addressing specific dimensions of sustainability, their development has often followed fragmented paths. Each framework has typically emerged in response to the priorities of its immediate context, whether regulatory, performative, or economic, leading to a landscape characterized by diversity, overlap, and partial convergence. Rather than forming a unified system, these approaches coexist as a constellation of methods that often address similar challenges from different scales and perspectives. Yet, despite their apparent dispersion, they collectively belong to a broader systemic effort to reconcile human activity with ecological limits. Recent research has emphasized the need to move beyond isolated tools toward more integrated and systemic interpretations of sustainability. In this view, assessment methods can be understood as operating across multiple layers of complexity, and for specific purposes. This multilevel perspective highlights how frameworks have progressively built upon one another, learning from previous limitations, refining indicators, and expanding their scope. In parallel, global policy agendas have provided shared reference points that have influenced the direction of sustainability efforts ^[67] ^[68].

Against this background, categorization becomes a necessary analytical step. Rather than treating each framework as an isolated instrument, this section seeks to map their common structures, recurring themes, and areas of emphasis. By situating these approaches within their historical development and aligning them with broader international sustainability milestones, it becomes possible to identify continuities, gaps, and complementarities among them. This categorization provides the foundation for a more critical understanding of how contemporary sustainable design workflows are shaped, and where opportunities for greater coherence and integration may still emerge.

After analysing the historical development of general sustainability frameworks, the focus now narrows to the group identified as *architectural certification systems*, including those selected for their widespread adoption or specific evaluative scope. To examine their internal structure and operative logic in greater depth, this research seeks to understand how sustainability is performed within architectural practice and, by extension, how it is implicitly defined through its evaluation mechanisms. Attention is therefore directed toward the indicators employed by each framework, as these constitute the operative translation of sustainability goals into measurable or verifiable requirements. The way indicators are selected, weighted, and combined directly shapes what is considered “sustainable” in practice, making them a critical object of analysis. By comparing different green building rating tools through their indicators, this research focuses on the cumulative conceptual construction these indicators generate together, offering a qualitative reading that goes beyond the numerical values or scores they ultimately produce ^[69].

This task is inherently complex due to the large number of indicators involved and the substantial variation in scope, typology, and intended application across certification systems. Frameworks such as LEED, for example, rely on extensive credit libraries from which project teams select combinations of criteria after meeting a limited set of prerequisites, while other systems allow wide variability depending on building type or regional context. A direct comparison at the level of individual indicators would therefore be impractical and potentially misleading. Certification systems differ not only in the quantity and formulation of indicators, but also in how mandatory and optional requirements are structured, which may lead to selective compliance and the omission of relevant sustainability aspects. Several studies highlight that some assessment tools still neglect certain phases of the building life cycle or prioritise easily achievable criteria over more impactful ones, ultimately limiting comparability and objectivity. These limitations reflect a broader tendency noted in the literature, where sustainability assessment is often treated as a series of technical issues rather than as part of a coherent, systemic and holistic approach. Consequently, no single certification system addresses all aspects of sustainability comprehensively, nor is there full consensus on what should be measured or how ^{[64][67][69]}.

In response to these challenges, this study adopts a category-based analytical approach. Instead of comparing indicators individually, they are abstracted into broader thematic categories that capture the underlying sustainability concerns they represent. This strategy enables a manageable and meaningful comparison while preserving the conceptual intent of each indicator. The resulting matrix cross-references the reviewed architectural certification frameworks with the categories they address, allowing areas of convergence, divergence, and omission to be identified. By shifting the focus from measurements to the qualitative structure of sustainability assessment, the analysis reveals which dimensions are consistently prioritised across frameworks, which are non-explicit or incidental, and which remain marginal or context-dependent, providing a critical view of current practices and leaning towards a more balanced sustainability evaluation in architecture.

DIAGRAM 3.B – Cross-Category Indicators Matrix.

Comparative study of macro-categories addressed across analysed frameworks, distinguishing explicitly defined indicators from indirectly or incidentally addressed aspects, evidencing areas of convergence, overlaps, and distinctions.

-  Incidental Indicator
-  Explicit Indicator
-  High incidence Indicator
-  Core Indicator across frameworks
-  Unique Indicator

		Frameworks								
		BREEAM	LEED	PHI	LBC	WELL	EDGE	ITACA	GRO	
Process	Integrative Process									
	Management									
	Project Priorities									
	Innovation									
Wellbeing	Health									
	Movement 									
	Nourishment									
	Mind 									
	Indoor Air Quality									
	Thermal Comfort									
	Sound									
	Light									
Resources	Materials									
	Waste									
	Circular construction									
	Energy									
	Water									
Environment	Site and Ecology									
	Pollution									
	Resilience									
Social Value	Transport									
	Equity									
	Community									
	Beauty 									

With the cross-category analysis we drove, a clearer picture emerges of the range, weighting, and preferences that contemporary sustainability assessments privilege or marginalise. One of the most evident outcomes of this comparison is the strong predominance of the “resources” macro-category, which is consistently addressed across all frameworks through multiple indicators related to energy, water, materials, and waste. Systems such as EDGE or Passivhaus are mainly based in this area of indicators based on performance targets and have only incidental impacts on other macro-categories. This prevalence can be linked to the factual and operational nature of resource-related metrics, which, as discussed throughout this chapter, allow sustainability to be translated into tangible, measurable, and reportable outcomes. These characteristics make resource indicators particularly effective as countermeasures to global crises such as climate change, where performance improvements must be quantified, benchmarked, and communicated. In this sense, the dominance of resource-related indicators reflects not only environmental priorities but also the practical requirements of regulatory, financial, and market-driven contexts in which these frameworks operate.

The second most recurrent macro-category, *wellbeing*, encompasses a much broader set of indicators. Its extent is largely influenced by specialised frameworks such as WELL, which place human health at the centre of assessment and articulate wellbeing through a vast range of indicators, including movement inside the projects and mental health as a unique approach among the rest of the analysed frameworks. Despite these differences in depth and granularity, wellbeing remains a highly relevant macro-category across most of the reviewed frameworks, often appearing through four or more indicator categories even when it is not their primary focus. This weighting is key to understanding current sustainable architecture practices, as it reveals a growing recognition of the role buildings play in shaping occupant comfort and health, while also exposing the uneven ways in which these aspects are operationalised.

At the same time, the analysis shows that several macro-categories receive significantly less attention, while other types of indicators like economic viability, long-term affordability, and broader socio-economic impacts are only marginally represented within most certification systems. This absence is particularly notable given the importance of economic considerations in both policy discourse and professional decision-making. With few exceptions, such as the cost-optimal methodology embedded in the EPBD discussed earlier in this chapter, economic indicators tend to remain external to certification logics. This imbalance highlights a recurring limitation in green building assessment tools, which often prioritise dimensions that are easier to measure and standardise, while leaving aside aspects that are more complex, contextual, or difficult to quantify ^[69].

It becomes evident that these methodologies strongly favour a green building perspective centred on meeting quantitative performance thresholds. However, they do not all operate according to the same logic, and this diversity is fundamental for understanding why such a

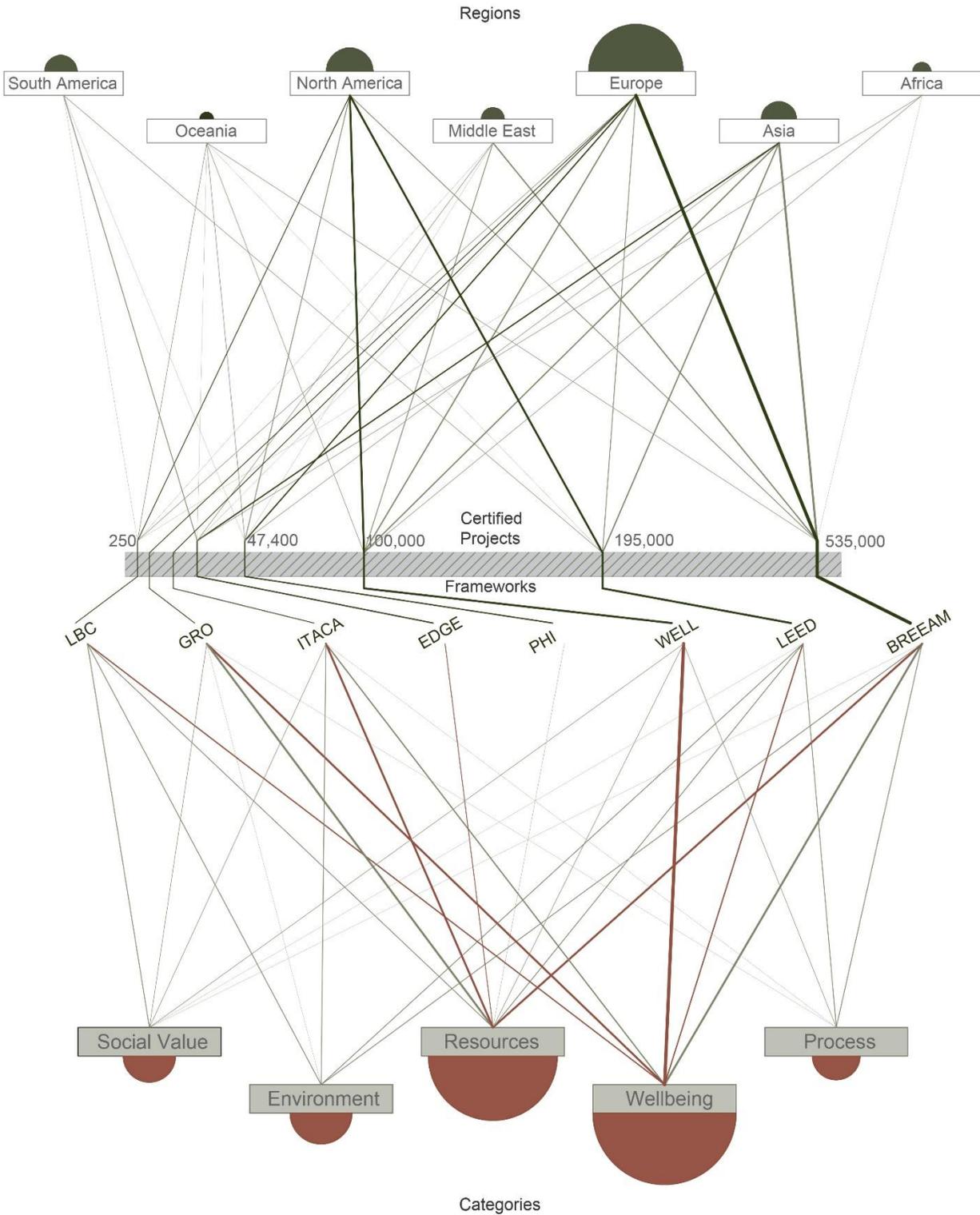
wide range of approaches coexist. Scope, therefore, becomes a critical variable in continuing to construct a definition of sustainable architecture, as each framework responds to different intentions, actors, and phenomena. Although visions of sustainable architecture can be traced back several decades, the rapid diffusion of green building practices over the last twenty to thirty years appears closely related to the consolidation of measurable performance indicators and, more recently, to the rise of circularity-oriented narratives. Concepts such as circular economy and green economy have reframed sustainability as a value-generating process rather than solely a damage-mitigation strategy. Nevertheless, the boundary between genuine alternative development pathways and opportunistic practices such as greenwashing can become thin, particularly when aggregated scores and symbolic recognition outweigh systemic transformation^{[67][69]}.

There is also a considerable difference in the goal of a certification depending on the actors, designers, developers, owners, tenants, and users who attach different expectations to sustainability and certification. Recent studies suggest that pursuing certification typically represents an additional initial investment ranging between 3 and 15 percent of construction costs, which explains why stakeholders seek a clear return on this effort. Developers frequently associate certification with higher sale prices, partly because improving resilience and reducing risk are increasingly valued in the real estate market. Owners tend to value certified buildings for their higher rental rates, improved occupancy experience, and slower depreciation. Tenants seem to be primarily attracted by operational cost savings and improved indoor environmental quality, which in non-residential buildings translates to staff productivity and reduced absenteeism, which are also linked to salaries and the organisation's costs. Moreover, a general industry recognition appears to be a commonly pursued benefit across most actors. These dynamics illustrate how sustainability frameworks have gained traction not only through ethical ambition but through their ability to align environmental performance with market logic^[70].

Although these dynamics extend beyond the central objective of this thesis, they provide an essential context for interpreting assessment frameworks. The core question remains how sustainable architecture can be meaningfully defined and evaluated. This chapter has revealed clear links between earlier theoretical visions of sustainability and the contemporary frameworks that operationalise them, while also exposing gaps, trade-offs, and inconsistencies. A building certified as “green” under a specific system may or may not align with broader sustainability definitions, depending on which dimensions are prioritised or omitted. To synthesise these findings, a final diagram has been developed based on official information and the previous count of indicator categories to illustrate the scope, scale, and relative weighting of the analysed frameworks, clarifying their geographical reach, weighted macro-category impacts, and revealing the bias imposed in the current analyses. This synthesis prepares the ground for the following chapter, which shifts the focus from assessment frameworks to their translation into everyday professional practice, examining how these logics are embedded within real projects and design workflows.

DIAGRAM 3.C –Frameworks Scope Network.

Traces the influence of the analysed frameworks through their regional extension, their relative size expressed by the official number of assessed projects, and the macro-categories they prioritise according to previous analyses.



Chapter 4

Case Studies

*“We can’t control systems or figure them out.
But we can dance with them!”*

-Donella Meadows

5.1 Methodology

After developing the theoretical analysis of sustainable concepts and assessment methods throughout the previous chapters, their translation into everyday architectural practice remains unclear. For this reason, the present chapter focuses on the study of built projects and professional workflows carried out by specialists in the field. A series of interviews was conducted with professionals across the countries in which this research has been developed: Belgium, as the host institution during the research period; Italy, as the academic base at Politecnico di Torino; Mexico, as the author’s country of origin with broad professional resources; and Switzerland, included for the valuable perspectives of experienced practitioners extending the research framework. This range allows observation of how sustainable assessment practices are applied under different regulatory, cultural, and professional conditions. The chapter is structured as case-based subchapters that combine professional insights with analyses of projects they have worked on, examining their process logic and reconstructing the typical toolchains involved. The aim is not to assess final performance results, but to identify similarities, interrelations, and potential gaps between theoretical frameworks and their practical application, using real design processes as a bridge between sustainability evaluation systems and architectural decision-making.

4.2 Belgium

ARCADIS - Rein Verrelst

Based in Antwerp, the Belgian office of Arcadis is primarily engaged in engineering and consultancy services, with a strong focus on infrastructure, building operations, and selected new construction and renovation projects, mainly within the national territory. The insights presented in this case are based on an interview with Rein Verrelst, a project engineer and environmental assessment specialist who graduated from Ghent University and has over thirteen years of experience in building performance evaluation. His work focuses primarily on office and industrial buildings, where sustainability assessments are typically conducted using frameworks such as BREEAM and GRO, depending on client objectives, budget constraints, and the project's initial positioning. When these frameworks do not fully align with project needs, Arcadis complements them with internally developed ambition-setting approaches that provide greater flexibility in the early design stages. According to Verrelst, an effective sustainability process ideally begins early and is grounded in the available architectural documentation, ranging from *BIM* models to simplified *SketchUp* massings, which support initial evaluations and goal-setting discussions with the client.

From these early meetings, the workflow centers on defining priorities and selecting a realistic set of criteria, rather than assigning equal weight to all credits. Typical toolchains include daylighting and dynamic energy simulations conducted in *DesignBuilder*, together with life-cycle and environmental impact assessments developed through *One Click LCA*, often directly based on BIM models. In parallel, Arcadis has developed internal *LCA quick-scan* tools to estimate carbon impacts at the earliest possible stages, even before detailed design decisions are made. The process is supported by continuous coordination meetings and usually concludes with an executive summary delivered in *PDF* format, while collaboration increasingly relies on shared digital environments and simplified BIM platforms. Verrelst highlights that budget remains one of the most decisive factors shaping sustainable outcomes and that the constant evolution of tools, manuals, and indicators makes these practices demanding to follow, yet remains one of the most stimulating aspects of contemporary environmental evaluation work.



DIAGRAM 4.2.1 – Arcadis BE
typical toolchain 2025.



Roeselare City Hall is a renovation project carried out by Arcadis between 2022 and 2024 that achieved a BREEAM *Excellent* certification and the first prize at the Belgian Construction Awards in the category of *circular building* and *climate responsibility*. The project exemplifies, at a built scale, under the collaboration of Rein Verrelst, the integration of a sustainability workflow into a coherent architectural outcome. Preserving the heritage value of the former town hall, with over 250 years of history, while seamlessly integrating a new extension developed under high sustainability and digital design standards. The intervention included a complete 3D scan of the existing building, converted into a BIM model and *Digital Twin* to support future maintenance and to enable a demolition inventory that identifies materials reusable on site or within the surrounding area. Among other innovations, the building is connected to a district heating network supplied with surplus energy from a nearby waste management facility, and together with on-site solar generation, this enables the project to achieve approximately 70% energy savings. The design prioritizes daylight and indoor comfort, ensures healthy ventilation, and promotes soft mobility through bicycle access, charging stations for electric vehicles, and strong public transport connections. Rainwater recovery systems and green roofs, enhancing biodiversity, further contribute to bringing the project's carbon balance close to zero, making it a strong example of a strategic, multi-layered sustainable renovation through cutting-edge technologies, and addresses contemporary challenges without compromising cultural heritage values ^[71].



Figures 4.1.2-4.1.4 – ©Arcadis ^[71].

Bureau Bouwtechniek - Jona Van Steenkiste

This architecture and engineering studio is characterized by a strong commitment to generating a positive environmental impact through technical expertise based in Antwerp. The office operates primarily in Belgium, with a particular focus on Brussels and Flanders, providing executive design, construction follow-up, and sustainability consultancy services to partner architects. The insights presented in this case derive from an interview with Jona Van Steenkiste, an architect and sustainability advisor who graduated from Ghent University and has over thirteen years of experience in circular design, life-cycle assessment, and environmental evaluation. His work primarily focuses on large-scale residential and office buildings, which are typically assessed under regulatory and regional frameworks such as *EPC*, *BREEAM*, and *GRO*, depending on the specific objectives of each project. According to Van Steenkiste, the sustainability process ideally starts as early as possible, preferably before the first sketches, by engaging with the design team to interpret client demands and consolidate an initial brief that clarifies intentions and priorities.

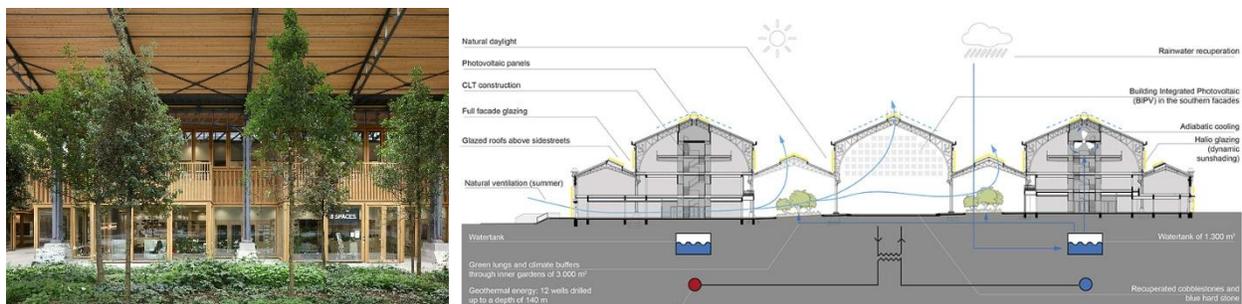
From this early involvement, design inputs typically arrive as PDFs, DWGs, or BIM models, and are followed by an incremental evaluation workflow that begins with materials analysis and then proceeds to energy performance. Life-cycle impacts are first explored using *TOTEM*, followed by building energy performance calculations through regional *EPB* tools and dynamic thermal and daylight simulations conducted with *CAPSOL*. A defining characteristic of Bureau Bouwtechniek’s approach is the frequency of interaction with the design team, often on a weekly basis, allowing sustainability advice to be integrated progressively rather than delivered as a single, final assessment. The process typically concludes with a dedicated meeting and a PDF report summarizing recommendations. Van Steenkiste notes that implementing sustainability measures often requires sustained effort to convince clients of their long-term value, with budget constraints frequently limiting the realization of proposed strategies to roughly half. He also highlights that applying multiple assessment frameworks within the same project tends to add unnecessary complexity and that defining project-specific priorities is more effective. Finally, he underscores the significant workload sustainability assessment entails, the limited integration of these processes into BIM workflows, and the ongoing challenge of aligning the perspectives of clients, designers, and consultants within a coherent decision-making process.



DIAGRAM 4.2.1 – B-B
typical toolchain 2025.



Gare Maritime is a former railway station in Brussels renovated between 2017 and 2020, with B-B responsible for the executive phase, and distinguished by a strong commitment to circularity and heritage preservation, recognized with a BREEAM Excellent certification. The intervention carefully safeguards the building's early 20th-century Art Nouveau character while adapting the three main aisles to host shops, showrooms, offices, and public spaces. A remarkable effort was made to retain existing materials, preserving approximately 90% of the original wooden roof structures, with only deteriorated elements replaced, while a modular construction logic was adopted to ensure future adaptability and reuse. The use of cement was deliberately minimized to reduce embodied carbon, favoring renewable and locally sourced materials such as cobblestones, bluestone, and timber components. Environmental strategies, including extensive greenery, natural ventilation, maximized daylight, geothermal heat pumps, rainwater harvesting, and solar cells located on the glass façades and roofs, contribute to a highly energy-neutral building. To manage the complexity of the project at this scale, the process relied on dense point-cloud surveys translated into an accurate BIM environment, enabling coordination across the many stakeholders and systems involved. Overall, the project stands as a clear example of a sustainability-driven architecture, in which circular principles, embodied carbon weighting, and human-centered value achieved exceptional spatial quality and exemplary performance [72].



Figures 4.2.2-4.2.4 – ©B-B [72].

4.3 Italy

Greenwich S.r.l - Beatrice Fanchini

Founded in 2007 and headquartered in Bergamo, with a more recent presence in Milan, the firm operates internationally with a strong focus on Europe and the Italian context. Its activity covers a wide range of environmental assessment and certification services for buildings, products, and organizations, working within ESG logics to enhance compliance, optimization, efficiency, and biodiversity. The insights presented in this case derive from an interview with Beatrice Fanchini, architect and sustainability consultant, with eighteen years of experience in environmental performance evaluation. She works within the Green and Healthy Buildings team, whose activity focuses mainly on office buildings, hospitals, hotels, logistics facilities, and data centers, frequently assessed under a very broad range of frameworks such as LEED, BREEAM, WELL, BiodiverCity, EarthCheck, and EPC, among many other options they offer depending on project typology and client requirements.

According to Fanchini, the consultancy process ideally starts at the concept design phase and may extend through construction management, although projects often arrive with limited documentation. Initial inputs typically consist of *DWGs*, *PDFs*, and narrative design reports rather than *BIM* models, allowing the consultancy to evaluate design outputs without directly shaping them. The workflow begins with a pre-assessment phase to identify the most relevant credits and realistic performance targets, which are then translated into a control table used to track project development. Energy performance is typically analyzed through dynamic simulations using *IES VE*, then supported in more detail by parametric studies developed in *Rhino-Grasshopper* with plugins such as *Ladybug* and *Honeybee*, while national regulatory compliance is verified through *Edilclima*. *Excel*-based tools are also used for additional calculations and coordination. The consultancy accompanies the project through all phases, delivering results through structured *PDF* reports and submission packages uploaded to certification platforms. Fanchini notes that minimizing design modifications is often crucial due to budget constraints and that while certification systems are regularly updated and technically robust, clients do not always fully understand the implications of each framework, reinforcing the importance of early engagement and clear prioritization.

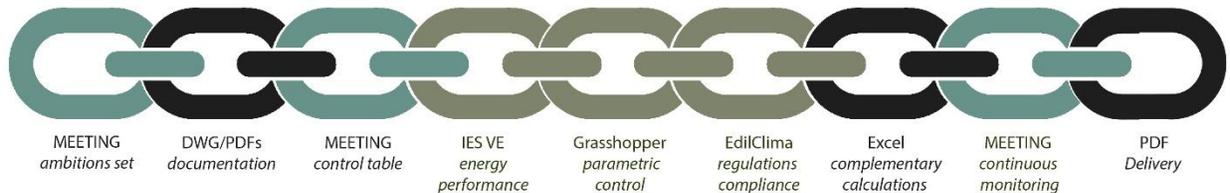


DIAGRAM 4.3.1 – Greenwich typical toolchain 2025.



Pirelli 10 is a large-scale regenerative project located in Milan, currently under development with environmental consultancy provided by Greenwich, and planned for completion by the end of 2026. The intervention transforms a former industrial complex into a mixed-use environment that hosts offices, retail spaces, food courts, and landscaped areas designed for social and everyday use, while also serving as an innovation hub connected to the University of Milano-Bicocca. Conceived as an urban forest, the project pursues an ambitious sustainability agenda, achieving high-level certifications including LEED Platinum, BREEAM Excellent, WELL Gold, and WiredScore, by contributing to urban biodiversity through the integration of more than forty plant species that enhance air quality, microclimatic performance, and user well-being for an expected population of over 5,000 occupants. At the urban scale, the project strategically reconnects the Bicocca district through a network linking green spaces, communal areas, and contemporary work environments, strongly supported by public transport and cycling infrastructure. Sustainability strategies emphasize a circular approach through the optimized reuse of materials recovered from the existing construction, combined with geothermal and solar energy systems to meet operational demands, and a carefully designed water cycle that integrates rainwater harvesting and the reuse of treated greywater for irrigation. Together with high indoor environmental quality standards and adaptable technological systems, these measures define a multi-layered project that addresses environmental performance, social interaction, generating a positive impact that extends beyond the site itself [73][74].



Figures 4.3.2-4.3.5 – ©BiM [74].

4.4 Mexico

Bioconstruccion y Energia Alternativa - Rosamaria Mellone

BEA is a pioneering firm in sustainability consulting and environmental certification in Mexico. Based in Nuevo León, with a more recent presence in Mexico City, the firm operates across key regions of the country, including major metropolitan areas and tourist destinations such as the Yucatán Peninsula and Baja California. Its activities are focused almost exclusively on consultancy services, including green building certifications, energy modeling, and commissioning. The insights presented in this case derive from an interview with Rosamaría Mellone, manager of commercial development, who shares more than fifteen years of experience in environmental evaluation. According to her, the firm works across a wide range of project typologies, including office buildings, industrial facilities, recently growing due to nearshoring dynamics, multifamily residential developments, and hospitality projects, where sustainability certifications are increasingly requested by international clients.

Mellone underlines the importance of integrating sustainability objectives from the earliest conceptual stages, as design changes introduced later in the process often generate significant economic impacts. BEA provides assessment and certification services under frameworks such as LEED, EDGE, WELL, EarthCheck, and national standards, depending on project typology and client commitment. The workflow typically begins with a diagnostic and feasibility phase that defines priorities, achievable credits, and responsibilities through a structured action plan. Preferred inputs include *DWG* files, *PDFs*, engineering drawings, and technical datasheets, as 3D models are rarely used directly for energy analysis and are often rebuilt by the modeling team into simplified geometries. Energy performance simulations are commonly carried out using *DesignBuilder*, while lighting and daylight analyses are supported through *AGi32*, with results consolidated into *PDF* reports and certification submissions. Although projects may be assessed under more than one framework, they generally align more closely with a single system depending on budget and scope, as requirements vary substantially, for example, between LEED and EDGE. Mellone notes that the largely voluntary nature of sustainability regulations in Mexico still limits widespread adoption, though growing ESG benchmarking practices and an increasing focus on resilience suggest a gradual shift toward more integrated sustainability approaches.



DIAGRAM 4.4.1 – BEA
typical toolchain 2025.



BEA347 Offices is the headquarters of BEA, located in Nuevo León, Mexico, constructed in 2011 and still fully operational. Conceived as a demonstrative project, the building was designed to showcase the studio’s sustainable design and consultancy capabilities, which led to its certification as LEED Platinum for New Construction at inauguration, reinforced through subsequent certifications, including LEED Platinum for Operations and Maintenance in 2015, WELL Certification in 2017, and a further LEED Platinum recertification in 2022, positioning the project as one of the first buildings in Latin America to achieve and maintain this level of performance over time. The building is characterized by an integrated water management strategy combining rainwater harvesting and greywater reuse, achieving savings of up to 76% consumption, alongside a diversified renewable energy system that supplies approximately 36% of its demand through photovoltaic panels, solar thermal collectors, and small-scale wind turbines. Complemented by extensive vegetation through green roofs, green walls, and indoor planting, the project integrates passive design strategies carefully monitored to ensure thermal comfort, adequate daylight, and high indoor environmental quality. Beyond its operational performance, BEA347 functions as a living laboratory, regularly used to demonstrate sustainable technologies and strategies to clients, professionals, and academic institutions, and stands as a pioneering reference for green buildings within the Latin American context ^[75].



Figures 4.4.2-4.4.4 – ©BEA ^[75].

Revitaliza Consultores - Heidi Valdez

Founded in 2009, is a recognized Latin American sustainability consultancy firm with a strong commitment to climate action, environmental justice, and the strategic use of smart technologies to promote sustainable innovation. The firm operates mainly as an independent consultant supporting third parties rather than engaging directly in design, offering services in building decarbonization, ESG strategies for real estate, and building certifications such as LEED, WELL, EDGE, Sustainable SITES, and BOMA BEST. With a strong presence in Mexico, particularly in the industrial north of the country, it also operates across Latin America and internationally, including projects in Peru, Spain, and the United States. The insights presented in this case derive from an interview with architect Heidi Valdez, Director of Experience, who has more than ten years of experience in environmental evaluation, supported by a longer professional background in conventional architectural practice. The firm primarily works on office and commercial projects, with a growing focus on industrial facilities in line with post-pandemic trends, and also engages in complex projects such as airports, stadiums, hotels, and large-scale infrastructure.

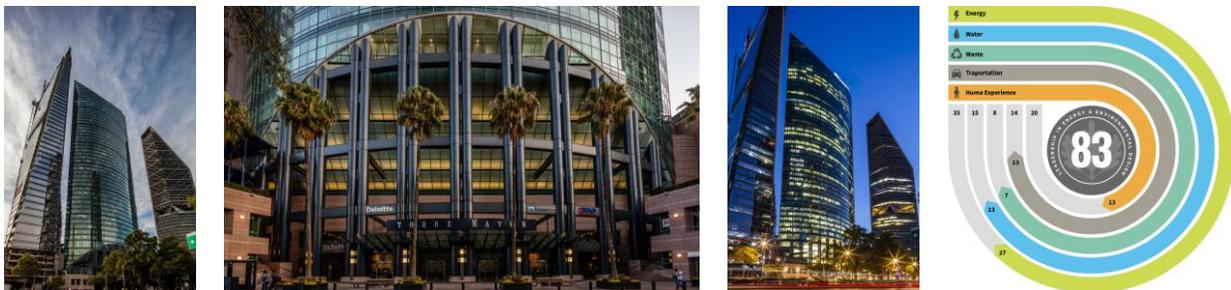
Their workflow typically begins once initial design concepts are defined, often before mid-design stages, followed by a feasibility analysis to identify achievable sustainability goals and the most suitable certification strategy. Project teams are then assigned clear responsibilities and coordinate through regular meetings every two to three weeks. Required inputs include architectural and engineering drawings, HVAC, electrical, and plumbing systems, material specifications, equipment datasheets, site location, and volumetric studies, all reviewed in parallel through centralized management platforms such as *Basecamp* to ensure coordination across disciplines. Performance assessments combine dynamic energy modeling using *IES*, embodied carbon analysis through *One Click LCA*, and climate resilience evaluation supported by *ClimateFirst*, with deliverables adapted to client requirements, ranging from certification-focused submissions to detailed technical reports. Valdez highlights that limited familiarity with sustainability among contractors often complicates implementation, reinforcing the need for continuous mediation between design and engineering teams. She concludes by stressing the lack of mandatory sustainability regulations in Latin America and the importance of education and systemic approaches, arguing that no single certification can address sustainability in its entirety and that meaningful progress depends on coordinated, complementary frameworks working toward shared objectives.



DIAGRAM 4.4.5 – Revitaliza C.
typical toolchain 2025.



Torre Mayor is one of the tallest buildings in Latin America, with 55 floors completed in 2003 as a corporate office tower in Mexico City's business district. After approximately eight years of operation, the building took a significant, ambitious shift, initiating a deep environmental upgrading process under the consultancy of Revitaliza Consultores. This process led to the achievement of LEED Gold for Existing Buildings: Operations and Maintenance in 2013, followed by successive recertifications in 2018 and 2023, the latter resulting in an upgrade to LEED Platinum alongside WELL Certification. To accomplish this requalification, the intervention focused on improving water efficiency through upgraded fixtures and the installation of an on-site wastewater treatment plant, which redirects treated water to cooling towers and sanitary uses, resulting in approximately 50% reduction in potable water consumption. On the energy side, the most recent recertification required the replacement and optimization of a large portion of the building's equipment, together with the implementation of an automated smart management system that enables real-time monitoring and interaction with energy performance, resulting in improvements of up to 85%. These interventions represent a complex challenge, as they were carried out on a fully operational building hosting more than seventy companies, requiring a strategic approach that allowed continuous operation while progressively correcting the environmental trajectory of a building not originally conceived with sustainability goals at its core [76].



Figures 4.4.6-4.4.10 – ©Revitaliza C [76].

4.5 Switzerland

Estia SA - Nathalie Dumas

This case presents a spin-off company that has worked in close synergy with the Building Physics Laboratory at EPFL in Lausanne since 1998, enabling continuous feedback between applied research and professional practice. This positioning allows ESTIA to translate research-based knowledge into concrete implementation of innovative sustainability approaches. The insights presented here stem from an interview with Nathalie Dumas, an engineer who graduated from EPFL, with over six years of experience in environmental performance evaluation and a longer background in sustainable energy systems. ESTIA's main line of work focuses on renovation projects, supporting compliance with Swiss legal energy requirements, including residential and heritage-valued buildings, mainly within the French-speaking regions of Switzerland, with occasional projects in the broader European context. The firm is typically involved when project complexity exceeds the scope of conventional architectural or engineering practices.

Projects usually reach ESTIA once a certain level of definition has been reached, often with incomplete or inconsistent initial information, requiring clarification and strategic reframing. The first step consists of understanding the client's motivation and defining how to approach the project, from the application of EPIQR methodologies to evaluate renovation costs and ecological impact, to alignment with national labeling systems such as CECB or performance-based frameworks like Minergie. Once the scope is defined, ESTIA coordinates the different project actors and carries out specialized analyses, including thermal calculations, grey energy assessment using *Lesosai*, lighting comfort simulations with *DIAL+*, and thermal bridge analysis through *FLIXO*, while continuously cross-checking results against cost implications via *EPIQR+*. When existing tools are insufficient, the company's research orientation enables the development of custom evaluation methods. The process typically concludes with *PDF* summaries and the preparation of official documentation required for labeling and regulatory approval. Dumas highlights that major challenges arise from extensive dialogue with clients who are often uncertain about their objectives, as well as from budget constraints that frequently limit the implementation of high-performance strategies, making negotiation and prioritization ongoing tasks. She also notes that qualitative aspects of sustainability are not always adequately represented within existing software or certification frameworks, despite their significant impact on occupants' experience. Ultimately, the complexity of the work lies in determining how far to pursue continuous improvement while balancing practical constraints.



DIAGRAM 4.5.1 – Estia.
typical toolchain 2026.



Ecoquartier des Plaines-du is a large residential development with integrated commercial spaces for the city of Lausanne, completed in 2024 and designed and constructed by Nicolas de Courten Architectes with sustainability assessment support from ESTIA. The project was awarded the Swiss Arc Award 2024, recognizing it as one of the most significant contemporary buildings in Switzerland. Its sustainable performance is characterized by an estimated 60% reduction in heating demand compared to conventional buildings, largely achieved through a high-performance building envelope based on highly insulating masonry systems with relatively low embodied carbon, alongside a deliberate reduction of concrete use limited mainly to slabs and essential structural elements. Heat production relies on a deep geothermal network combined with heat recovery from wastewater, significantly lowering operational energy demand at the district scale. The project achieved an excellence Minergie-P label, ensuring high standards of energy efficiency and indoor comfort, and is also aligned with the Swiss 2000-Watt Society objectives, limiting the energy use per person and associated CO₂ emissions. Beyond its technical achievements, Plaines-du-Loup demonstrates how key sustainability targets can be effectively met within large-scale developments while remaining economically viable and attractive to developers, without relying on excessive additional investment, thereby keeping green solutions accessible to a broader segment of the population ^[77].



Figures 4.5.2-4.5.4 – ©Nicolas de Courten architectes ^[78].

Chapter 5

Conclusions

*“Stories should never end,
but rather lead to further stories”*

-Anna Tsing

5.1 Critical Perspectives

This thesis has focused on exploring the multiple dimensions that come into play when attempting to define sustainable architecture beyond the canonical definition issued in the Brundtland Report in 1987. It seeks this meaning through its actual practice, where sustainable architecture appears deeply intertwined with a cluster of highly convergent disciplines that, surprisingly, still **lack a stable definition** capable of clarifying the complex interrelations between the different dimensions of the environmental narrative. Rather than being analyzed as isolated fields, as has traditionally been the case, these diverse perspectives collectively outline a shared concept, intrinsically dynamic due to its collective composition as a plural entity capable of adapting to an infinite range of contexts and needs. This same complexity renders it elusive to static definitions, and the absence of consensus surrounding the vast terminology that comprises it makes it particularly urgent due to the relevance of the subject in the context of global crises. The effort of this thesis to pursue such a definition through its historical development is necessarily partial, nevertheless, it represents a meaningful anthological step that few authors have approached from this perspective. Ultimately, it should be understood not as a conclusive statement, but as an invitation to a deeper collective dialogue aimed at guiding the discipline toward a shared understanding.

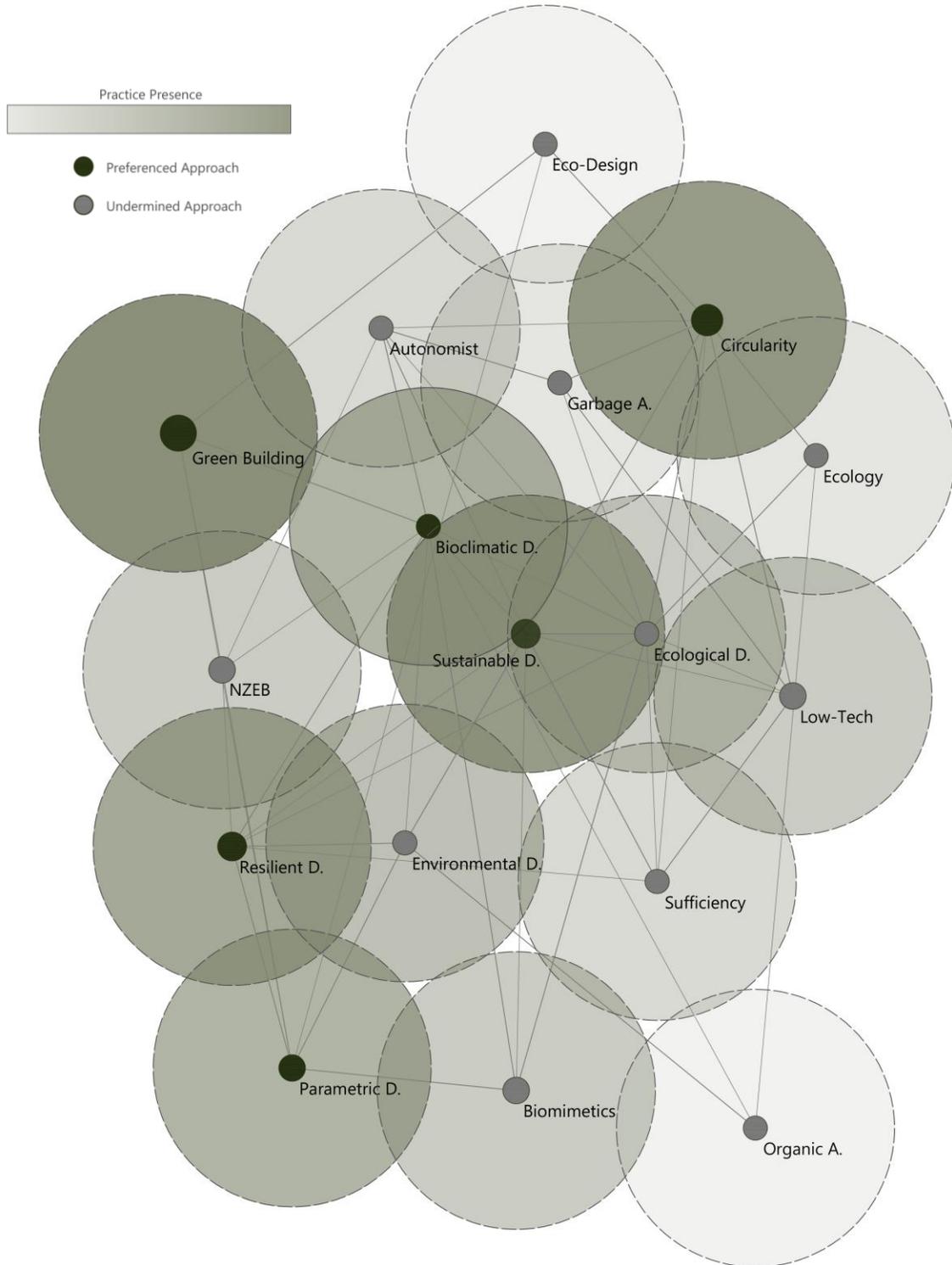
The large number of terms used within the field of sustainable architecture stems from parallel developments that emerged under different contexts and with subtle shifts in focus, proliferating mainly over the last century. This growing tendency has intensified as the climate struggle has shifted from a revolutionary, niche-based concern to a large-scale environmental awareness effort. The outcomes of this transition have been ambivalent, ranging from a tangible increase in collective attention toward the environmental impacts of our actions, to the spread of phenomena such as greenwashing, which have found market value grounded in a genuine interest for products and services that claim an ethical quality of environmental responsibility, yet are not always consistent when subjected to rigorous scrutiny of their actual results. Within this panorama, a **market preference** has also emerged for practices largely aligned with the valorization of a green capitalism, often favored over more radical visions that advocate for deeper systemic change. This dynamic has resulted in the widespread adoption of approaches such as *Green Building*, while others, such as *Low-Tech*, remain marginally applied, confined to specific situations, and frequently maintain an almost experimental character.

Likewise, the absence of a shared and consolidated epistemological foundation leaves room for virtually anything to be considered “green”. Since sustainability is, by nature, a highly flexible category capable of encompassing a wide plurality of visions, the risk grows alongside the critical effort required to discern what truly belongs within it and what does not. When everything can be regarded as sustainable, **the term itself gets diluted** and loses its meaning. This condition highlights the importance of clarifying definitions, not with the aim of rigidly standardizing them, but of re-anchoring sustainability within a shared conceptual framework. Such an effort cannot be individual; it requires coordinated collective action, not to continue coining ever more specific terms, nor to arbitrarily privilege certain visions over others, but to move beyond disciplinary trenches and academic egos and to compose a joint endeavor that transcends labels. These labels ultimately become irrelevant or indistinguishable when the debate is framed either around *Sustainable Architecture*, *Bioclimatic Architecture*, or *Environmental Design*. Contributing to a common body of knowledge ultimately offers greater value than continuing to fragment it.

At the same time, it is precisely this **plurality of voices** that gives sustainability its richness. Local adaptations, cultural interpretations, and contextual responses expand its meaning far beyond any canonical definition. The challenge, therefore, lies not in suppressing diversity but in strengthening epistemological awareness of how these perspectives relate to one another. A more serious engagement with the shared history of sustainable architecture, one that neither excludes nor diminishes approaches developed in different geographical or cultural contexts, would help foster a more robust understanding of the field. The limited presence of *environmental design* within European research traditions, or the uneven academic treatment of *ecological design* across universities, are examples of gaps that continue to shape both professional and academic practice. Addressing these omissions would contribute to forming both more critical researchers and better-informed practitioners, capable of engaging sustainability from a deeper and more coherent foundation.

DIAGRAM 5.A – Sustainable Architecture Presence Network.

Building on the previously developed semantic network, this diagram illustrates the overlapping sustainability approaches and their presence in practice, as observed across the frameworks, workflows, and projects analyzed.



Under this lens, an additional tension emerges between **academic discourse and professional practice**. While universities continue to advance on increasingly incisive research, operating under highly sophisticated standards aimed at minimizing environmental impact, reducing energy consumption, and incorporating extensive social studies to ensure design responses aligned with their context, a clear disconnection persists with the everyday practices of sustainable construction. These practices tend to be far more pragmatic, confined to specific fields of action and driven by fixed guidelines that often lie beyond the architect's control.

Even within the limited study presented in *Chapter 4*, which does not aim for statistical representativeness, a tendency can be observed to favor consolidated and internationally recognized environmental assessment schemes such as *BREEAM* or *LEED* over independent sustainability evaluations or local frameworks. Beyond this, a significant **disparity can also be observed between countries** that lead the sustainability agenda, such as Belgium or Switzerland, and other contexts. The presence of thoughtful infrastructure, national frameworks, autonomous tools, and clearly defined priorities, together with higher budgets, enables a superior standard of excellence. Within these conditions, solutions such as on-site generation of high shares of renewable energy, the use of high-quality materials, such as highly airtight windows, and the integration of advanced technologies are often taken for granted, allowing the discourse to shift toward more complex issues that extend beyond the project's operational phase.

By contrast, in other realities such as Mexico or many developing countries, the sustainability agenda is frequently reduced to minimal or even nonexistent mandatory environmental requirements. In these contexts, sustainable practice tends to be confined to a limited sector of companies or high-income clients who can afford medium and long-term investments, and who seek a clear return on the additional cost that sustainable construction represents, particularly as alignment with internationally recognized brands continues to carry greater market value.

These tendencies are strongly grounded in economic criteria. Since the earliest definitions of sustainability, the economic dimension has been repeatedly acknowledged as one of the discipline's pillars. Moreover, as observed throughout practice, it often proves to be decisive in determining both the scope and the direction of a project. For this very reason, the **limited presence of an economic perspective** within theoretical visions and its relatively restricted scope even within practical frameworks appear striking. This observation exposes a structural weakness in the sustainability discourse, where the economic dimension, despite being critically decisive, remains insufficiently addressed. While design studios tend to recognize this clearly from the outset, the available tools remain limited. Economic analysis is only marginally addressed in a few frameworks, such as the *EPBD*, which suggests approaches like cost-optimal analysis, or national schemes such as the Swiss *EPIQR*, which places a strong emphasis on economic evaluation. The *EDGE* system, in turn, does not provide direct economic assessment tools, yet functions as a mechanism for value generation and for reinforcing potential investment in projects.

Although these tools are already diminished, they largely operate within a management-oriented logic, and truly innovative proposals, such as *Doughnut Economics*, alongside other strands of circular visions, remain far from being fully embedded in everyday practice. Beyond approaches that merely soften the impacts of a consumer-driven society, a profound paradigmatic shift is required, one that truly aligns with sustainability goals and enables **new ways of assigning value**, in order to avoid the absurdity of restricting environmental improvement measures simply because they fail to meet short-term investment timelines. Economic aspects continue to be treated as secondary constraints rather than as active drivers of sustainable transformation, even though the opposite is often the case in practice.

Likewise, the **social dimension is addressed in an uncertain manner**. While it is extensively covered within theoretical views, its presence within professional assessment schemes is significantly reduced, particularly when compared to resource-related indicators. Beyond this imbalance, it becomes even more complex to determine whether existing social indicators are adequate or not. As architects, the lack of specific expertise in this field inevitably limits the depth of analysis that can be undertaken. Nevertheless, the low level of importance assigned to social criteria remains evident, as does the inherent difficulty of reducing complex human conditions to numerical values within a table.

Moreover, in professional practice, this dimension proves equally challenging to address, given that among the studios consulted during research, social analyses were rarely conducted beyond what was explicitly required by certification systems, revealing a profound detachment of the dimension from the general green evaluation. In most cases, responsibility for addressing social aspects rests with the design architect, who often operates under significant constraints imposed by client demands. As observed in the research, these demands tend to prioritize maximizing economic returns, further limiting the scope for meaningful integration of social considerations into the project.

It is important to stress that this critique does not position quantitative evaluation methods as flawed or inadequate. On the contrary, performance-based tools, indicators, and certification systems have proven extremely effective in addressing immediate, measurable outcomes, particularly in areas such as energy efficiency, resource optimization, and emissions reduction. Their capacity to translate complex phenomena into comparable metrics has been decisive in developing useful, sustainable practices. Due to this simplifying nature, sustainability assessment gets reduced to a series of checklists, thresholds, and numerical benchmarks that privilege those dimensions that can be reliably measured, modeled, and standardized over interpretative understanding. While such reductions offer certain operational advantages, they inherently restrict these systems' capacity to engage with deeper qualitative dimensions. As has been observed, the growing reliance on quantitative frameworks risks shifting sustainability from a critical design question to a procedural exercise. In an era characterized by uncertainty, complexity, and what has been further described in *dark naturalism*, such reductionism risks oversimplifying realities that demand critical interpretation.

For this reason, the integration of **qualitative perspectives is not optional, but necessary**. Contemporary environmental conditions are defined not by linear cause-and-effect relationships but by entangled, nonlinear interactions that resist complete quantification. An approach that is mainly focused on complying with measured environmental targets would most likely result in an efficient asset rather than genuinely livable and meaningful spaces. Expanding evaluation frameworks to include cultural, social, and ethical dimensions allows sustainable architecture to move beyond performance alone and to operate as a creative expression of emerging values and paradigms. Sustainability, in this sense, should not be understood solely as a technical objective to be achieved, but as a cultural project shaped by collective values, contextual awareness, and interpretative judgment. By adopting a broader lens, sustainable architecture can appropriately engage with the multi-layered realities of the present and contribute to shaping environments that are not only efficient but also meaningful.

Within this context, **toolchains acquire a critical relevance**. As this research has shown, digital workflows, simulation environments, and assessment tools are not neutral instruments, they actively shape architectural practice by framing decisions, prioritizing certain parameters, and marginalizing others. Before design intentions are formalized, toolchains have already defined what can be evaluated, optimized, and compared, subtly guiding architectural outcomes. The growing reliance on automated processes and data-driven design amplifies the influence of these toolchains. While such systems increase efficiency, precision, and the capacity to handle complex datasets, they also risk embedding assumptions that remain largely unquestioned within everyday practice. Aspects that are more difficult to integrate or do not come as compulsory steps of frameworks tend to be easily neglected, in this sense, toolchains do not only support decision-making but actively participate in it. Without such critical awareness, there is a predisposition for leaving architectural authority displaced by tools themselves, reducing sustainability to what can be computed rather than what can be created.

As technology increasingly merges with everyday life, the capacity for critical judgment must grow proportionally. Navigating the *Technocene* requires not only better tools but more conscious designers, professionals capable of questioning the assumptions behind the data they use and of maintaining agency within highly mediated design environments. In this context, the challenge no longer lies only in accessing technological capabilities, but in understanding how they shape perception, priorities, and architectural outcomes. As several perspectives of environmental theory have emphasized, technological systems are never neutral, they embody specific values, epistemologies, and power relations that condition both what can be known and what can be acted upon. Accordingly, sustainable architecture is tendentially less about mastering technological systems and more about cultivating the critical awareness needed to guide them responsibly.

5.2 Future Research

The present research aimed to illustrate a broad range of topics related to constructing a collective picture of the multiple dimensions involved in defining sustainable architecture, without elaborating too deeply into any single one. This necessarily synthetic approach leaves several lines of inquiry open for further development. Many of the aspects addressed throughout the thesis would benefit from a more focused investigation, potentially incorporating additional perspectives that could contribute to a more robust and shared understanding of the field.

Following the structure of the thesis, *Chapter 2*, dedicated to the historical development of sustainability-related architectural thought, presents a particularly interesting ground for future research. While ancient architectural responses to environmental conditions have been extensively studied, the modern and **contemporary timeline** remains fragmented. Existing anthological efforts often break into disciplinary trenches or are shaped by strong theoretical biases, resulting in partial or discontinuous narratives. Further research aimed at developing a more integrated and shared historical account capable of bridging a significantly stronger epistemological foundation.

Likewise, the extension presented in *Chapter 3* could be expanded by incorporating a wider range of evaluation systems and **assessment methodologies**. Extending the scope of the comparative analysis would allow for a more comprehensive mapping of convergences, overlaps, and persistent gaps across sustainability frameworks. Such an expansion could also move beyond category-level comparisons toward a more granular investigation of individual indicators, enabling a more precise discussion on their relevance, accuracy, and weighting under specific contextual conditions. This line of research could contribute to a more critical understanding of how sustainability metrics are constructed and applied in practice, moving toward punctual suggestions for complementary qualitative approaches.

Regarding *Chapter 4*, the exploratory nature of the case studies suggests multiple opportunities for further investigation. A broader, more representative sample of architectural and consultancy offices, tailored to clear geographical and regulatory contexts, could provide a clearer, more tangible picture of prevailing professional workflows. This would help identify recurring patterns, structural constraints, and concrete areas of opportunity within sustainable practice. Moreover, a more detailed and systematic **examination of toolchains** emerges as a particularly promising direction for future research. Scrutinizing each stage of the design and evaluation process, examining what is prioritized, what is overlooked, and how decisions are progressively constrained could reveal underlying dynamics that remain largely implicit in current practice. Such insights would be essential for a better understanding of how sustainability is operationalized, negotiated, and ultimately shaped within contemporary architectural production.

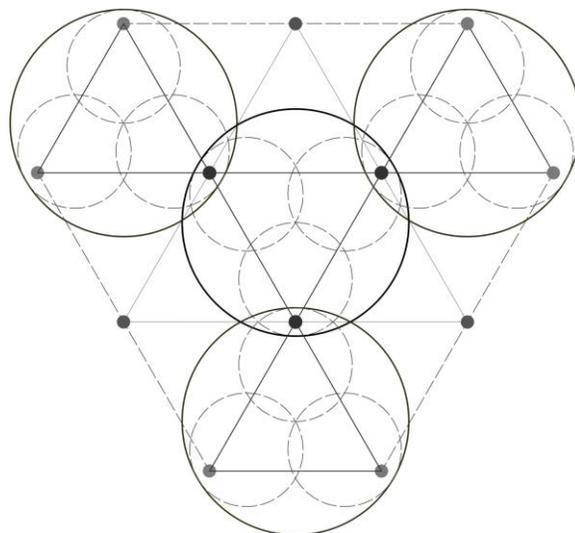
5.3 Final Remarks

Despite how straightforward the definition of sustainable architecture might appear, it proved challenging to define based on its actual practice. The partial definition we began to draw by mapping its history, perspectives, interrelations, and workflows should therefore be understood as an initial step rather than a conclusive result, one that remains inevitably shaped by my own interpretative position. For this reason, the following points of view should not be taken as decisive conclusions, but rather complementary visions on the collective endeavor of environmental thinking.

- *There is a lack of consensus regarding definitions, shared history, and interrelations, this thesis places a modest step toward a shared dialogue on it.*
- *Certain approaches are more widely disseminated than others as a result of their alignment with dominant societal values.*
- *Disciplinary fragmentation dilutes the meaning of sustainability, allowing an indiscriminate use, making critical interpretation and collective efforts essential.*
- *Sustainability gains its richness from the coexistence of multiple voices, privileging none over others reinforces its capacity to address multilayered problems.*

- *There is a disconnection between the depth of academic theory and the scope of standardized professional practice.*
- *Marked disparities between countries, shaped by unequal resources and regulatory frameworks, result in uneven sustainability practices.*
- *Despite its decisive role, the economic dimension remains weakly addressed across sustainability frameworks.*
- *The social dimension remains difficult to operationalize for architects and is largely reduced to simplified metrics within building certification systems.*
- *Quantitative evaluation methods are effective, yet their reductionist nature prevents them from capturing the full complexity of sustainability.*
- *Qualitative integration enables sustainability to emerge as a meaningful mode of expression and reaction within contemporary practice.*

- *Toolchains subtly shape and constrain sustainable architectural outcomes in ways that should not be underestimated.*
- *As technology rises and automates processes in our lives and jobs, the critical judgment to examine these results needs to grow accordingly*



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