PROPOSITION AND DISCUSSION ON LOW-CARBON BUILDING TECHNOLOGY - LCBT

PROPOSIÇÃO E DISCUSSÃO DE PRINCÍPIOS PARA TECNOLOGIA CONSTRUTIVA DE BAIXO CARBONO – TCBC

PROPUESTA Y DISCUSIÓN DE TECNOLOGÍAS CONSTRUCTIVAS BAJAS EN CARBONO - TCBC

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ABSTRACT
Society has faced the unique challenge of reducing CO2 emissions associated with its productive activities. Such a goal is particularly relevant to the construction sector, which accounts for 37% of global greenhouse gas emissions. However, the initiatives undertaken in the sector have not yielded satisfactory results. This article proposes and discusses principles that contribute to the formulation and development of low-impact building technologies. The hypothesis is the organization – a central aspect of technology – of architectural production significantly contributes to its unsustainability. Logical argumentation supported by a literature review on technology, sustainability, and low-carbon practices was employed as a methodological approach and the outcome involved identification and characterization of seven principles, namely, permanent building, non-alienated labor, man-nature integration, less energy, self-determination, productive rationality, and popular empowerment. The principles define Low-Carbon Building Technology and suggest a framework for reorganizing production processes so that they become less carbon-intensive.

KEYWORDS
Building technology; Low-carbon; Concept; Modes of production; Civil construction.

RESUMO
A sociedade se encontra diante de um desafio ímpar: reduzir as emissões de CO2 relacionadas às suas atividades produtivas. Trata-se de uma das metas da construção civil, a qual emite 37% do montante de gases de efeito estufa, globalmente. As ações empreendidas neste setor, contudo, não têm demonstrado resultados satisfatórios. O objetivo deste artigo é propor e discutir princípios que contribuam para a formulação e o desenvolvimento de tecnologias construtivas de menor impacto. Parte da hipótese de que a maneira como se organiza a produção da arquitetura é o que a torna mais insustentável, sendo esta organização um aspecto central da tecnologia. Como abordagem metodológica foi empregada a argumentação lógica, apoiada na revisão da literatura sobre tecnologia, sustentabilidade e baixo carbono. O resultado da pesquisa consiste na nomeação e caracterização de sete princípios denominados edificação permanente, trabalho desalienado, integração homem-natureza, menos energia, autocentramento, racionalidade produtiva e poder popular. Em conjunto, delimitam Tecnologia Construtiva de Baixo Carbono e indicam uma forma de rearranjar os processos produtivos para torná-los menos intensivos em carbono.

PALAVRAS-CHAVE
Tecnologia construtiva; Baixo carbono; Conceito; Modo de produção; Construção civil.

RESUMEN
La sociedad se enfrenta a un desafío sin precedentes: reducir las emisiones de CO_2 derivadas de sus actividades productivas. Este es uno de los principales objetivos del sector de la construcción, responsable del 37 % de las emisiones globales de

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gases de efecto invernadero. Sin embargo, las acciones llevadas a cabo en este sector no han producido resultados satisfactorios. Este artículo tiene como objetivo proponer y discutir principios que contribuyan a la formulación y al desarrollo de tecnologías constructivas de menor impacto ambiental. Parte de la hipótesis de que la forma en que se organiza la producción arquitectónica es lo que la hace más insostenible, siendo esta organización un aspecto central de la tecnología. Como enfoque metodológico, se empleó la argumentación lógica, respaldada por una revisión de la literatura sobre tecnología, sostenibilidad y bajo carbono. El resultado de la investigación consiste en la identificación y caracterización de siete principios denominados: edificación permanente, trabajo no enajenado, integración humano-naturaleza, menos energía, autocentrado, racionalidad productiva y poder popular. En conjunto, estos principios definen lo que se entiende por Tecnología de Construcción Baja en Carbono e indican una forma de reorganizar los procesos productivos para hacerlos menos intensivos en carbono.

PALABRAS CLAVE

Tecnologías constructivas; Bajo en carbono; Concepto; Modos de producción; Construcción civil.

1. INTRODUCTION

Rising temperatures, global warming, greenhouse gases (GHGs), climate adaptation plans, resilience, mitigation, and vulnerability have been widely disseminated by the media, gradually extending beyond the scientific domain due to climate change. In turn, there is growing consensus within the scientific community that the human development model is the primary cause of such changes (IPCC, 2022). Some scientists have even argued that human activity has been responsible for systemic transformations on a planetary scale, considered decisive for the beginning of a new geological epoch currently referred to as Anthropocene, Capitalocene, Corporatocene, or Plantationocene (Marras & Taddei, 2022).

Despite the different designations and interpretations regarding causes of the aforementioned situation, the crucial point is the disruption of the planet's climate balance directly affects the conditions that led to the current stage of human prosperity, threatening the physical, mental, and food security of society (IPCC, 2014) and existence of various species. The importance of discussing global warming lies in ensuring the minimum conditions for survival in a scenario where the limits of prudence have already been exceeded (Lowe, 2012; Marques, 2020). The issue is no longer on mitigating to preserve, but rather on adapting life to a diverse and increasingly unpredictable world.

The warning signs of this tension date back to the 1960s, when the first studies pointed to an environmental crisis defined by three main factors: a) humanity was consuming more resources than the environment could regenerate, with population growth continuously intensifying this pressure; b) waste generation exceeded the natural assimilation capacity; and c) a wide range of pollutants was being released into water, air, and soil from multiple sources (Saramago, 2023). Since then, collaborative efforts have been made to understand the consequences of environmental degradation for both the planet and humanity, leading to seminal works such as Silent Spring (Carson, 1962), The Population Bomb (Ehrlich, 1968), The Tragedy of the Commons (Hardin, 1968), and the reports The Limits to Growth (Meadows et al., 1972), Only One Earth (Ward & Dubos, 1973), and later Our Common Future (WCED, 1991), initially published in 1987 and also known as the Brundtland Report. The Intergovernmental Panel on Climate Change (IPCC), established in 1987, was tasked with compiling studies aimed at clarifying the specific effects of rising greenhouse gas concentrations on Earth's systems, and has since published periodic reports on climate change.

Although an extensive body of data and scientific projections support that phenomenon, there has been significant resistance from society and its representative institutions to implementing actions truly capable of minimizing both causes and effects of global warming. The Kyoto Protocol has proved insufficient (Souza; Corazza, 2017) and it is now widely acknowledged that the Nationally Determined Contributions (NDCs) proposed by various countries under the Paris Agreement must be more ambitious if the goal is to limit the increase in global average temperature to no more than 1.5°C above pre-industrial levels (Tsai et al., 2024).

Such a lack of decisive action is due to, among other reasons, global warming challenging the economic system based on the logic of production growth, which serves as the reference for the definition of the Gross Domestic Product (GDP) of several countries and is the leading indicator of development and progress. Production growth is presented in the GDP framework as a mechanism for improving social well-being (If more is produced at a lower cost, more people will be able to have their essential needs met) and maintaining the system itself, ensuring social order and the international power structure (Latouche, 2009; Sachs, 1997). The "extract – transform – discard" motto is emblematic of contemporary society (EMF, 2015), even though not all cultures are based on that assumption.

Given our social division of labor, the productive system is essential for generating the goods necessary for human survival. However, while increasing production surpluses seemed crucial for centuries, production now threatens human security (Marques, 2020). It must be highlighted that the goods produced have not been distributed equally or fairly across society, as historically claimed, considering persistent social inequality, income concentration, poverty, and chronic hunger (Oxfam, 2017). Fundamentally, that is a distribution problem, since the proclaimed comfort and security are not based on meeting human needs and the most basic ones, such as adequate food, water, and housing are rather based on the consumer's purchasing power (Andrioli, 2009).

Even if equal consumption were ensured for the entire global population according to the standards of so-called developed countries, humans would face an unavoidable problem of insufficiency of environmental resources (Boff, 2015; WWI, 2010), since physical and natural factors impose limits on economic growth. Economy fundamentally depends on both extraction and use of matter and energy supplied by nature and humans cannot produce any material goods without relying on those finite natural resources (Georgescu-Roegan, 2012). Rethinking the meaning of development and social progress has thus become a key factor in discussions on sustainability and climate change (Tavares; Chiletto; Ino, 2022). The rationalization of those resources has prevailed to date and, according to Georgescu-Roegan (2012), prolongs our existence as we know it, but does not exempt us from an imminent collapse.

2. CIVIL CONSTRUCTION, LOW CARBON, AND SUSTAINABILITY

Research on sustainability in civil construction is extensive and well established, with an increasing focus on carbon reduction. Energy, the central theme of the recent discourse, is the primary source of greenhouse gas (GHG) emissions globally due to its widespread use in various human activities such as goods production, building operation, transportation of people and goods, communication, food preservation, healthcare, among others. Consequently, energy efficiency and development and adoption of new energy sources have become pressing and tangible demands.

The following two relevant considerations must be highlighted: 1) social demand for energy continues to grow, and, to date, no energy source has been simultaneously economical, abundant, and highly efficient as fossil-based ones (Marques, 2020); and 2) energy demand, in its various forms and continuous growth, results from the way production, distribution, and consumption of human creations are organized. In other words, the conflict lies within a broader context, i.e., in the material reproduction of life, a human choice socially enacted by its representatives and those who hold decision-making power (currently, the owners of substantial financial resources invested in large corporations).

In that regard, focusing efforts solely on energy efficiency or altering the energy matrix enable the perpetuation of the economic system through the preservation of fundamental resources necessary for sustaining production and consumption (O'Connor, 2000), as in the rationalization of material and water use (Acselrad, 2002). The approach is also supported by the Brundtland Report, which prescribes sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs (CMMAD, 1991). Under that framework, a false sense of proactivity in favor of the climate arises, resulting in little real progress given the continual increase in greenhouse gas emissions, when their levels should instead be decreasing. Moreover, loopholes open to label products or buildings as sustainable or low-carbon when they are not - a "status quo of sustainability" approach (Hopwood; O'Brien, 2005) often promoted through the management of environmental resources (Saramago; Lopes, 2023).

2.1. The need for a new approach

The construction sector plays a vital role in promoting social well-being, for it is responsible for the development of buildings and infrastructure. The transformation of natural resources through labor, materials, tools, and technical knowledge is achieved through various means, processes, and methodologies that create safe and functional spaces supporting human development and workforce renewal. Additionally, due to its extensive supply chain, labor-intensive operations, and broad range of activities, the sector drives capital flows and generates significant employment. Given its scale and capacity to stimulate related services, industries, and jobs, civil construction is considered a strategic component of national economies and public policy agendas (Campos; Guilhoto, 2017). Therefore, it is mandatory to consider the entire production process, from decisions on the use of material resources, labor, energy, tools, and capital, to the understanding of the way choices made in one area may significantly influence others.

The discussion presented here explicitly addresses the technological dimension of construction. Since the Industrial Revolution, technology has been understood as the theoretical organization of technical knowledge (Lopes, 2006). Construction technology refers to the systematized body of theoretical and practical knowledge that enables the production of buildings and their components, including gestures, timing, and physical forces. It encompasses aspects related to materials, labor, means of production, and the foundational knowledge involved (Tavares, 2024), all of which are structured into processes, procedures, and methods that determine how and why certain materials, techniques, or tools are used. Among other factors, it identifies those who hold the productive intelligence, the time, and the conditions (Gama, 1987).

Technology is a social construct, i.e., it is neither neutral, nor immutable, but somewhat shaped by the interests of the dominant class within a specific historical and spatial context (Harvey, 2016; Feenberg, 2002). No technology is proposed independently of the prevailing mode of production. Preference is currently given to natural resources that are accessible, abundant, and inexpensive, processed in centralized production units, and transformed into construction materials and components through energy-intensive means that generate substantial waste and pollution. Such products are distributed over long distances via integrated transport networks heavily reliant on fossil fuels. The overarching goal of the entire process is to increase production while simultaneously reducing time and costs and ensuring economic viability and profitability.

One of the core mechanisms of capitalist accumulation operates according to the following logic: the more and the faster the production, the greater the number of items available for sale at a lower cost. Expanding production is, therefore, essential for enhancing investments in the means of production (e.g., physical space, machinery, and labor), maintaining a company's competitiveness in increasingly saturated markets, and, above all, ensuring profit generation (Marx, 2013). Such operational logic is also presented as a (false) justification for making goods more accessible to a broader population. However, it ultimately promotes the homogenization of construction alternatives in culturally and geographically distinct territories, disregarding local potential, knowledge, and traditions (Magnaghi, 2011).

Increasing production inevitably entails greater exploitation of natural resources, heightened generation of pollutants and waste (even when subject to rationalization), and encouragement of consumption. In most cases, the relevance or actual usefulness of what is produced is not questioned; the central aim is to maintain high manufacturing output to sustaining continuous consumption and keeping the economy active. Technologies are, in general, conceived and implemented within that same paradigm (Harvey, 2016).

Latouche (2009) highlighted compensatory technology, which anticipates repairing potential damage from its use - not to mention the need to create corrective technologies that fix an undesired effect of a previous technology (Huesemann; Huesemann, 2011). In both cases, a business opportunity is generated with little reflection on the problem's causes and the solution's effects. In general, problems are regarded as a necessary evil or a risk to be faced towards the collective good, when it is known that damages usually concentrate in some territories and among specific populations (Saramago; Lopes, 2024; Chomsky; Pollin, 2020).

Such productivist and consumerist logic can be exemplified in the construction industry context as follows. Urban boundaries are expanded to addressing the identified housing deficit through the construction of new residential units and supporting urban infrastructure, including roads, public lighting, drainage networks, sanitation and water supply systems, public transport lines, schools, daycare centers, health clinics, and public green spaces. New construction technologies, often industrialized, rationalized, or even sustainable, are employed in those developments. They are designed to ensure speed and cost-effectiveness while meeting the minimum performance criteria established by ABNT NBR 15.575 standard (2021).

Despite the absolute need for new housing, 27% of the housing deficit in Brazil correspond to substandard dwellings (FJP, 2023), which require specific and tailored responses for promoting improvement. The industrial productivist logic rarely meets those responses. Furthermore, it is observed that several municipalities choose to build new units even when the number of vacant and/or abandoned properties exceeds the demand for new buildings, or when the excessive burden of rent per household prevails. Although such a practice generates new business opportunities and stimulates local economy, it fails to address more complex issues (e.g., the social function of land). 52.12% of the national housing deficit is related to excessive rent burdens (FJP, 2023), which refer to constructed assets and environmental and social resources invested. Access to housing might be solved through alternative means; however, the favored solution is the one that promotes capital accumulation.

The large-scale production of units homogenizes spatial and construction solutions, disregarding family size and cultural and climatic contexts. On the other hand, the model is accompanied by issues such as land concentration, socio-spatial segregation, and gentrification and requires exploitation of additional environmental resources, even when what is already built and consolidated could be optimized. Operating within that context involves complex challenges, such as private land ownership. However, on the other hand, we are haunted by climate change and its various disasters stemming from how we interact with the world.

In that regard, framing the discussion on sustainability around the development of new technologies, when technologies aim to improve, enhance, and maximize the efficiency of production processes and, ultimately sustain the continuous production growth, is insufficient and even contradictory, given the challenges posed. It is essential to rethink technology and advance in addressing the fundamental issues that underpin it.

Based on the foregoing, this paper proposes and discusses principles that can contribute to both formulation and development of alternative construction technologies capable of reducing greenhouse gas emissions within the sector. The principles consider the construction industry context beyond a mere building object and define and characterize "Low-Carbon Building Technology" (LCBT).

3. METHODOLOGY

This research is based on the hypothesis that the organization of architectural production is the primary factor that contributes to its unsustainability. Therefore, it is essential to rethink the technology developed for building construction.

The conceptualization and characterization of Low-Carbon Building Technology comprise Phase 1 of the research project entitled "Low Carbon Building Technologies - LCBT: Timber and New Paradigms for Architecture and Construction", developed by the Housing and Sustainability Research Group (Habis) at the University of São Paulo. The principles were established through logical argumentation, a methodology that supports a coherent framework delineating the proposed theoretical construct.

The research design was structured into three phases, namely, 1) state-of-the-art review or strategic conceptual mapping, 2) analysis and synthesis of the mapping results, and 3) definition of the principles and formulation of the argument.

Phase 1 focused on three key concepts, namely, a) Technology, b) Sustainability, and c) Low Carbon. Understanding what technology and construction technology are, their assumptions and implications, and the processes through which they are developed and disseminated was essential to underpin the research aimed at developing a concept of technology. In turn, "low carbon" and "sustainable" were considered qualifying concepts for the technology to be proposed and conceptualized. Therefore, discussions on those topics, including their outcomes, contradictions, limitations, and potentialities were mapped and analyzed. The result of the literature review mapped the main talks on low carbon and sustainability, drawing from general literature (other fields of knowledge) and specific literature (architecture and civil construction). The approach is justified, since the specific literature shares broader discussions and its actions are often conditioned by them (e.g., how the Rio 92 conference fostered initiatives within the construction sector through agreements and policies).

In Phase 2, building on the strategic mapping previously developed, the following objectives were a) to understand the actions and processes that contribute to GHG emissions in architecture and civil construction, as well as other negative impacts related to their contradictions and shortcomings, and b) to identify the actions and processes necessary for an effective reduction of those emissions and to mitigate other associated negative impacts, addressing their potentialities and possibilities. The results of are summarized in Table 1, whose organization was based on three guiding questions, namely, a) How do greenhouse gas (GHG) emissions occur during building construction? b) What are the other associated negative impacts?, and c) What actions and processes are necessary to effectively reduce GHG emissions and other impacts and foster more accessible, scalable, and equitable human development? In response to them, the following thirteen situations were identified and mapped.

Sources of GHG emissions	Additional adverse impacts	Potential Solutions	Authors
1) By considering **nature** as an **inexhaustible source of resources** (both material and energetic), or merely as a manageable source of such resources;	Waste, improper use, depletion of essential resources; land use exploitation and change; destruction of biomes and biodiversity;	Productive rationality; durability; circularity; passive architecture; prioritize renewable-source materials; apply Life Cicle Assessment (LCA); apply the 8Rs; reduce consumption;	Meadows (1972); Daly (2012); Ward, Dubbos (1973); Acselrad (1993); Layrargues (1997); CMMAD (1991); Bonaiuti (2016); Kibert (1994);

Sources of GHG emissions	Additional adverse impacts	Potential Solutions	Authors
2) Considering **nature as external to human beings**, and that humanity controls all variables of its existence through technological development;	Destruction of biodiversity; species extinction; air/water/soil pollution; occupation of areas that could be preserved; alteration of the landscape; need for corrective technologies;	Durability; circularity; LCA; rethinking the way buildings and cities are implemented; prioritizing the use of renewable materials; 8Rs; humans and nature as rights holders;	Georgescu-Roegan (2012); Gudynas (2011); Bonneuil, Fressoz (2024); Rockström et al. (2009);
3) Considering the negative impacts (social, environmental, economic, cultural) as **externalities** of the production process;	Air/water/soil pollution; poisoning; social inequality; destruction of people/cultures and biomes; alteration of land use;	Incorporate the costs of impacts into products to encourage the search for new solutions; implement eco-taxes; highlight impacts through LCA; pursue systemic and transdisciplinary understanding of decisions;	Georgescu-Roegan (2012); Daly (2012); Furtado (2012);
4) By prioritizing **decisions**, at all stages of civil construction, following the logic of productive rationality, productivism, and aiming for economic viability;	Increasing exploitation of resources and associated pollution; worsening labor conditions; concentration of profits and wealth; growing inequality; obsolescence; creation of needs; unnecessary production of goods;	Add other variables to the decision-making process beyond productivity; include additional variables in cost composition; change the arrangement of people involved in decision-making; apply LCA; educate society for value change; generate quality employment;	Latouche (2009, 2010); Acosta (2016); Silva, Silva, Agopyan (2003); Duplessis (2002); Rios, Chong, Grau (2015); Viola, Basso (2016);
5) By turning everything into **disposable products**, not subject to reuse or maintenance, aiming at the continuity of production and consumption; 6) By **wasting materials** and generating waste at all stages of a building's life cycle;	Need for exploration of new resources and continuous extraction of raw materials; depletion of essential resources; use of land for waste disposal; generation of pollutants; destruction of biomes; land-use change; creation of large landfills;	Durability; circularity; LCA application; professional training for renovation, maintenance, and dismantling of buildings; construction management; 4Rs (Reduce, Reuse, Recycle, Recover); productive rationality; rationalized design; circular production; implemented and enforced public policies for final waste disposal, reuse, and recycling; use of simple (non-composite), minimally processed materials;	CMMAD (1991); Kibert (1994); Kallis, Demaria, D'Alisa (2016); Latouche (2009, 2010); Daly (2012); Sachs (1986); UNFCCC (1997); Duplessis (2002); Rios, Chong, Grau (2015); Kibert, Chini, Languell (2001);
7) By **universalizing solutions** aimed at cost reduction – design, materials, work arrangement, methods of execution;	Disregards local specificities and potentialities as well as human creative capacity; increases GHG emissions during transportation and distribution stages;	Decentralize, diversify, consider local characteristics and potentialities; promote the economy by using local resources (materials and labor);	W. Sachs (1996); I. Sachs (1986); Santos (2003); Latouche (2009, 2010); Acosta (2016); Duplessis (2002); Magnaghi (2011);

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Sources of GHG emissions	Additional adverse impacts	Potential Solutions	Authors
8) By valuing **mass production** to reduce costs, disregarding the diversity of needs and solutions;	Disregards social diversity; creates monotonous spaces; contributes to social and spatial segregation; reduces labor cost by simplifying it, stripping it of meaning;	Diversify housing typologies considering different family arrangements; develop techniques suitable for renovation and maintenance, training professionals, and generating dignified employment and income opportunities; take local characteristics into account;	Duplessis (2002); Rios, Chong, Grau (2015); Gonçalves, Duarte (2006); Schneider, Till (2005); Esteves (2013); Giesekam, Barrett, Taylor (2016);
9) **Concentrate** income, decision-making power, knowledge, and means of production, disregarding social, cultural, and territorial diversity;	Capital accumulation and concentration; increase in social and political-economic inequality; increased production to sustain the business; devaluation of the multiplicity of solutions;	Social participation; collaboration; mutual aid; knowledge sharing; decentralizing means of production; distributing income through dignified and skilled work; prioritizing transdisciplinarity;	Daly (2012); Acosta (2016); Latouche (2009); Dawood et al. (2013); Schumacher (1981); Magnaghi (2011);
10) Increasing consumption of **energy** (both operational and embodied), driven by continuously growing demand and centered on fossil fuel sources;	Need for increased energy generation; pollution and destruction of biomes; geopolitical conflicts; recurrent use of public subsidies;	Passive design; use of renewable energy; building energy efficiency; substitution of energy-intensive materials and components; prioritizing local solutions and materials; using efficient machinery and minimally processed materials; harnessing the power of photosynthesis; conserving energy;	Silva (2000); I. Sachs (2002, 2007); UNFCCC (1997); Duplessis (2002); Luo et al. (2019); Patil, Kumthekar (2016); Pomponi, Moncaster (2016); Luo et al. (2019); Shove (2018);
11) Prioritizing **cost over the quality**, performance, and long-term usefulness of the building;	Low durability of the building and its components; generation of waste; need for new resource extraction to replace damaged parts;	Ensure passive environmental comfort, accessible renovation and maintenance, quality and performance of used components; rethink building design and technologies considering the possibility of rehabilitation, renovation, expansion, and disassembly;	I. Sachs (1986); Duplessis (2002); John et al. (2002); Finch (2009); Devecchi (2010);
12) High CO_2-emitting **materials** used in a disposable manner, as well as toxic or somewhat toxic materials that cannot be reincorporated into nature;	Pollution and destruction of biomes; increased need for landfills; generation of waste; expansion of landfills and disposal areas; low awareness in the sector;	Establish policies that restrict the use of high-impact materials, increasing their reuse and recycling; choose materials that act as carbon sinks, tend toward neutrality, or are biodegradable; prioritize local materials; implement ecotaxes, public policies, legislation, and regulations; propose credit lines and research funding, as well as education and training programs for new practices; opt for materials and systems that are reusable;	I. Sachs (1986, 2002); Daly (2012); Takano (2015); Duplessis (2002); Rios, Chong, Grau (2015); Kibert, Languell (2001); Huang et al. (2018); Luo et al. (2019); Peñaloza, Erlandsson, Falk (2016); Pittau et al. (2019); Howe (2015); Shi, Yu, Zuo (2015);
13) By depriving the various **agents** in the sector of understanding the impact of their actions and choices based on profit and "progress".	Permanent environmental impacts; implementation of partial or self-interested solutions; lack of awareness of new practices.	Educate (universal and professional education); provide access to tools; create collective decision-making spaces; strengthen regulatory institutions.	Sachs (1986); Wang et al. (2016); Duplessis (2002); Shi, Yu, Zuo (2015); Giesekam, Barrett, Taylor, (2016); Ferro (2018); Magnaghi (2011);

Table 1: Literature mapping in response to the guiding questions.

Source: Elaborated by the authors. Adapted from Tavares (2024).

In the third phase of the research, the information was categorized into themes that ensured coherence across the dataset while avoiding repetition or content overlap. Three grouping proposals were developed, resulting in the diagram shown in Figure 1.

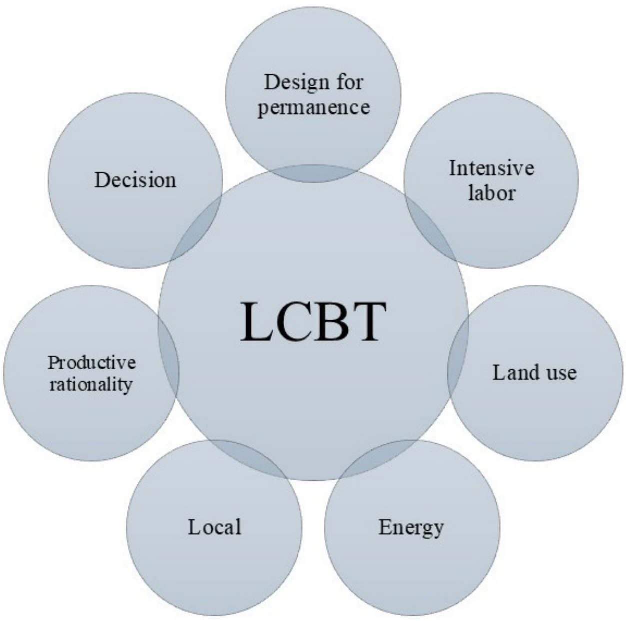

Figure 1: Diagram of the seven categories of analysis.
Source: Elaborated by the authors. Adapted from Tavares (2024).

Each category was presented, described, and justified; its objectives and the prescriptive aspects applicable for the development of an LCBT (Low-Carbon Building Technology) were outlined. A new literature review explored issues not addressed in the previous phases.

Finally, a new synthesis effort was undertaken towards the definition of the principles by posing the following question: "If the development of an LCBT (Low-Carbon Building Technology) involves issues raised by the analytical categories, what specific features of each category determine the different principles of an LCBT?" The outcome of the process is summarized in Table 02.

The broader research also sought to establish relationships among the various principles and understand their mutual influences. It mapped the agents and actions required to make the proposal viable and speculated on processes that could enable new approaches to inhabiting the world. This article focuses on the discussion of the seven principles that define and characterize LCBT.

Concept	Analysis category		Principles
Low-Carbon Building Technology (LCBT)	Design for permanence	->	Permanent building
	Intensive labor	->	Non-alienated labor
	Land use	->	Man-nature integration
	Energy	->	Less energy
	Local	->	Self-determination
	Productive rationality	->	Productive rationality
	Decisions	->	Popular empowerment

Table 2: LCBT Categories and Principles.
Source: Elaborated by the authors. Adapted from Tavares (2024).

4. RESULTS AND DISCUSSION – PRINCIPLES FOR A LOW-CARBON BUILDING TECHNOLOGY

Low-Carbon Building Technologies result from a set of seven independent yet complementary principles aimed at supporting the creation, refinement, and dissemination of construction technologies that minimize GHG emissions from the production of the built environment, but are not limited to that. The proposal also fosters meaningful improvements in people's quality of life by enabling dignified means of material and social reproduction and recognizing civil construction involves much more than building structures. The principles point to a new way of organizing production, redefining its purpose and the way it is conducted, encompassing labor, materials, tools, territory, and people. The seven principles are presented in what follows.

Principle 01: Permanent building

The principle advocates for preserving and optimizing all natural resources extracted (e.g., raw materials, water, and energy) by valuing the environmental, social, and financial efforts invested in the construction of buildings and their components. It aims to avoid further extraction and reduce waste generation, greenhouse gases, and various pollutants related to the construction process. It does not prohibit replacing building parts, but prioritizes maintenance of the primary structure´s functionality and preservation of the existing urban infrastructure. Additionally, it emphasizes the reuse of previously employed components, encouraging actions that promote reuse and recycling towards the same goal.

Permanent building assumes:

- Application of principles of flexible and adaptable design that promote easy renovation and maintenance, enabling buildings to accommodate different uses or needs over time;
- Assurance of construction, spatial, and environmental quality for avoiding demolitions and need for new buildings;
- Use of materials that can be employed in multiple technical cycles, prioritizing those that are non-toxic, minimally processed, simple (rather than composite), and of standardized or modular dimensions;
- Design for assembly, disassembly, and deconstruction, incorporating simplified and accessible mechanical connections between components, with weights compatible with human lifting capacity;
- Training and qualification of labor at all levels of action, with a focus on demolition, disassembly, renovation, and maintenance of buildings;
- Promotion and strengthening of a market niche for previously used materials such as those from demolitions or disassemblies, through laws, financing programs, and credit lines.

As previously discussed, the proposal for permanent buildings incorporates concepts of circularity and design for assembly, disassembly, and deconstruction. Regarding durability, it aims to go beyond conventional logic based solely on the relationship between initial cost and warranty period, a rationale often used to justify solutions that intensify negative environmental impacts by disregarding factors such as material origin, reuse and recycling potential, and methods of processing and final disposal.

According to John et al. (2002), durability is not an inherent property of the material, but rather, the result of a set of decisions and actions spanning the design and construction phases, as well as environmental conditions, usage, and exposure of the building along with maintenance, which must also be planned during design. In this context, the use of natural, minimally processed, or even biodegradable materials may be a viable option if replacements and maintenance are anticipated over time without compromising the overall safety and stability of the structure.

Principle 02: Non-alienated labor

This discussion aims to promote forms of labor in which productive intelligence belongs to the worker, ensuring autonomy in the production process and fostering knowledge expansion, rather than concentration. Daly (2012) argued that shared knowledge has a multiplying capacity and should not be treated as a scarce resource. However, since knowledge confers power, withholding it becomes a form of control, especially by keeping workers - particularly those on construction sites - in a state of alienation. This explains the strong emphasis on labor division and specialization, task simplification, and structuring of production in ways that reduce the worker to a mere executor of external orders, operating at a pace not determined by themselves. The issue, therefore, is not merely a lack of qualified labor, as often claimed in the construction sector, but rather, a deliberate devaluation and underpayment of site work, which makes it unattractive and actively discourages the professional development of workers, thus limiting their bargaining power (Ferro, 2018). A worker with more knowledge and know-how will naturally seek better working conditions, just like anyone in any sector of the economy.

Alienated, subdivided, and simplified labor is one of the key mechanisms of the current mode of production, employed to reduce the cost of labor, hence, the price of products (Marx, 2013). It results from the organization of productive arrangements that centralize manufacturing in large hubs and rely on complex supply and distribution networks, which are feasible only for large-scale production. Such a scale is necessary to amortize the high fixed capital costs and lower production costs per unit. The model concentrates power, capital, and profit while disregarding alternative construction methods or local business models rooted in practices and opportunities specific to each region. Consequently, traditional and local knowledge is gradually diluted.

Considering this discussion and aiming to overcome it in certain aspects, the concept of non-alienated labor proposes:

- Development of non-alienating production processes and construction components, elements, or systems in which the worker fully understands the tasks performed, has mastery of the tools used, and are free to propose solutions. The goal is not to simplify processes for accommodating low skill levels, but to promote worker training so that they can competently perform their functions;

- Promotion of worker training through comprehensive learning that encompasses both theoretical and practical knowledge and is not limited solely to the specifics of their trade, ensuring autonomy and room for creativity;
- Valuing of labor and workers by establishing laws and regulations that recognize the importance of various professions and ensure safety and rights of workers
- Promotion of methods of organizing work and workers based on small businesses or cooperatives geographically dispersed and aligned with local demands and opportunities. Decentralized, smaller-scale operations are advocated.

In this context, the aim is to overcome the logic of concentration easily observed in physical objects such as industrial conglomerates, by addressing something immaterial and less visible: knowledge. The concentration of knowledge impacts social organization and everyday life practices, influencing professions, determining the value of labor, and leading to disappearance of trades, resulting in devaluation or undervaluation of workers, who become increasingly “disposable.” The process also affects territorial organization and the overall quality of life of the population.

Principle 03: Man-nature integration

The way natural resources are exploited is impactful, predatory, and reckless, especially considering people´s dependence on them for survival. Historically, nature has been regarded as an infinite source of resources, resilient to interference, and as a suitable space for the disposal of various types of waste. However, land use - whether through occupation or alteration of its functions for resource extraction - has directly affected the planet’s natural cycles, causing impacts that cannot be reversed by isolated, partial technological solutions.

Towards changing such a way of operating, humans must recognize they are part of nature and their survival and interaction activities must be aligned with natural cycles. In this context, the following actions are proposed within the field of civil construction: 1) avoidance of use of highly polluting materials and energy - and carbon-intensive processes, 2) increases in the use of resources from renewable sources, and 3) promotion of circularity in the production and use of construction materials (UNEP, 2023). Since all of them impact land use and land-use change, the proposal of LCBT requires:

- Promotion of the use of materials and resources in ways that reduce pressure on land, by specifying those that can be reused or recycled, thereby avoiding premature disposal and need for new resource extraction;
- Promotion of the use of materials and resources from renewable and biodegradable sources, supporting the preservation of non-renewable and/or scarce resources, while always prioritizing low-carbon production and construction processes;
- Respect to the characteristics of the local environment during siting of buildings for avoiding drastic changes to the terrain and disruption of the local ecosystem;
- Prioritization of selection of local materials and resources, preserving traditional cultures and ways of building, even if revised and adapted to contemporary needs;
- Promotion of actions throughout the construction industry's supply chain that generate positive environmental impacts and contribute to both maintenance and enhancement of ecosystem services

Respecting natural cycles and avoiding environmental degradation would result from a new attitude towards the world.

Principle 04: Less energy

As addressed elsewhere, energy production and use are central themes in discussions on sustainability and low-carbon strategies. Reducing and avoiding energy consumption are a main priority in the construction and use of buildings, even surpassing the importance of improving energy efficiency and switching energy sources, which are also essential. In this regard, LCBT should consider:

- Avoiding energy use by eliminating the need for its production and consumption through a) reductions in the amount of materials used in a building by eliminating unnecessary steps, streamlining construction processes, and minimizing waste, b) choice of less processed or less energy-intensive materials, c) specification of locally sourced materials for reducing transportation demands, d) assurance of proper environmental performance of buildings by avoiding mechanical equipment and prioritizing passive comfort strategies;

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- Rationalization of energy use by prioritizing high energy-efficiency systems, tools, and machinery at all stages of production (from material manufacturing to construction) and during the building's use and occupancy;
- Choice of renewable energy sources for both production and use of buildings.

Principle 05: Self-determination

The capitalist production system is characterized by the standardization and uniformity of products, processes, relationships, and people, universalizing lifestyles. It is a monoculture that affects what is produced, the way it is produced, the materials used, and the way people live (W. Sachs, 1996). Such uniformity stems from the productive efficiency required for viability, based on repetition and mass production principles. On the other hand, towards social acceptance of that production, efforts and resources are invested in advertising and marketing for persuading people from different regions to desire the common overcoming local beliefs and traditions. Furthermore, reducing production and distribution costs creates unfair competition with local producers.

According to Magnaghi (2011), that mode of production directly impacts territorial organization, since territories are used merely as technical support for specialized productive activities, thus interfering with people's understanding of the context in which they live and diminishing local possibilities in favor of the demands of an increasingly globalized market. In the author's words:

> The local territory is no longer known, interpreted, or experienced by its inhabitants as the source of elements necessary for the reproduction of biological life (water, springs, rivers, air, soil, food, fire, and energy) or social life (neighborhood, community, symbolic relations, etc.). The dissolution of places and their transformation into amorphous dust within the broader framework of a process of deterritorialization of life definitively produces a total loss of sovereignty of individuals and local communities over the material, social, cultural, and symbolic forms of their existence (Magnaghi, 2011, p. 282, our translation).

The idea of self-determination is a counterpoint to that trend, since it proposes the construction of a political and economic alternative based on territory (Acosta, 2016). It involves decentralizing decision-making control, creating opportunities from within the territory outward, and valuing local resources and needs. Participation, autonomy, solidarity networks, decentralization of productive units, knowledge, and power, as well as diversity of solutions are key concepts in this discussion

Aligned with those objectives, LCBT proposes:

- Recognizing and utilizing local conditions and resources such as climate, construction techniques, cultures, unique characteristics, materials, energy sources, and knowledge towards promoting varied solutions tailored to each context, fostering greater harmony with the territory;
- Recognizing the value of people and encouraging collective agreements to boosting social cohesion, empowerment, and community autonomy. Therefore, it requires promotion of active participation and establishment of collective spaces for decision-making and knowledge exchange, thus fostering the development of a community based on dialogue and diversity;
- Encouraging local development through technologies adapted to a reduced production scale using simple and accessible tools and machinery. The goal is to generate jobs and income in the region, foster creativity and autonomy among the professionals involved in the production process, and facilitate training and knowledge exchange among participants in the production cycle.

Principle 06: Productive rationality

In the face of an environmental collapse and the intrinsic need to extract, exploit, and use resources for construction production, such activities must be performed rationally, avoiding waste or loss. The optimization of the use of a resource avoids its exploitation at the source, thus minimizing inherent impacts. The so-called externalities of the production process must be rethought as integral elements of the production chain, internalizing their impacts. In this sense, LCBT should consider:

- Ensuring the optimization of resource use in the construction of a building and its components, eliminating waste, residue generation, and material loss, as well as energy, human effort, water, and production time;
- Reducing resource consumption by eliminating unnecessary construction steps, especially

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those used to hide construction process flaws or interface errors, properly sizing materials by applying the minimum of them required to ensure adequate safety and comfort for users, and minimizing distances between materials and the construction site;
- Promoting circularity principles in production through waste management and utilization, material reuse, and design for disassembly for maximizing the lifecycle of a resource extracted from nature.

Principle 07: Popular empowerment

The discussion on "popular empowerment" proposes decentralizing decision-making power by promoting the participation of agents besides those who hold capital and means of production towards establishing goals that surpass the logic of productivity, multiply solutions, and prioritize human life on a planet with finite resources. From such a perspective, LCBT should:

- Promote the active participation of diverse agents, representatives, and collectives in the design phases of construction technologies towards a collaborative, eclectic, and multidisciplinary approach without hierarchies. The goal is to create solutions that appropriately address the group's needs and represent their realities;
- Foster collective arrangements that strengthen the autonomy and self-esteem of groups;
- Adopt a grounded and conscious approach to each choice's environmental, social, cultural, political, and economic impacts, use analytical tools such as Life Cycle Assessment (LCA), Ecological or Water Footprint, and develop other tools to assess quantitative effects;
- Be revolutionary, since those choices must be grounded in new social relations, hence, in transformations of production relations.

4.1. Discussion

This research is based on the hypothesis that the way architectural production is organized makes it a more unsustainable activity. It argues practical solutions cannot be proposed without breaking away from the paradigm of the current mode of production, in which:

- Nature is understood as an inexhaustible source of resources and as something external to human beings;
- Negative environmental impacts are considered externalities of the production process, a price to be paid for progress;
- Wastefulness and disposability prevail;
- Decisions remain concentrated within certain groups, similarly to knowledge, income, and means of production;
- Economic viability is the determining factor in decision-making;
- Dependence on energy is increasing;
- All social, territorial, climatic, and environmental diversity is disregarded;
- There is no robust, socially shared understanding of the impacts of human actions.

Greenhouse gas (GHG) emissions and other environmental and social impacts result from decisions that perpetuate those productive assumptions, although production rationality focused on resource efficiency is a present concern.

According to Arthur (2009), the conception of a technology begins with the formalization of a technical problem to be solved along with its justification, followed by the definition of possible solutions that consider the phenomena to be overcome. Both formulation of the problem and its solution are choices aligned with the interests of specific human groups. Although they have been based on paradigms over the past three centuries, they are now known to directly contribute to climate change.

With a basis on a literature review and logical argumentation, this study defined and characterized seven inseparable principles that, together, assist in the formulation of a low-carbon construction technology when considering:

- The produced asset, its design, and the production of its components and systems, aiming at its maximum permanence;
- The labor involved, the tools, and the knowledge about the production process, encouraging autonomy and multiplication of ways of doing things;
- The human relationship with nature, respecting its natural cycles, promoting actions that impact the environment positively, and collaborating with ecosystem services;
- The reduction of energy demand by first avoiding its consumption and then by promoting optimized forms of use based on renewable sources;
- The social, environmental, cultural, and economic characteristics of different territories, multiplying

and diversifying solutions, decentralizing, dispersing, and reducing the scale and complexity of productive units;
- The mode of production, valuing the maximum and best use of resources;
- The way of deciding and evaluating the impacts of different needs and solutions beyond what is economically viable.

Which material should be selected among the wide range of available materials? Such a choice must consider aspects that enhance discussions on Low-Carbon Building Technology (LCBT), placing the material at the center of the diagram, as shown in Figure 2. The same approach should be applied to the other components of technology.

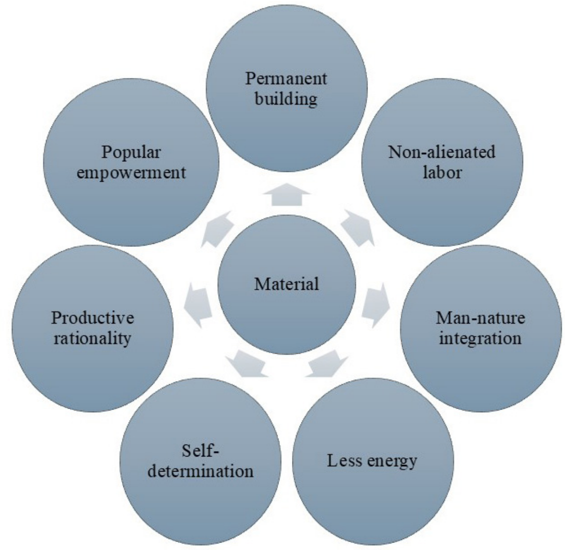

Figure 2: Principles to be considered for the selection of construction material.
Source: Elaborated by the authors.

Diagram 1 summarizes the process for the development of a technology based on Arthur (2009) and the constituent parts of construction technology, according to the theory developed by Gama (1986). The objectives of technology and the values that will guide the solution are defined in the process. This research advocates the seven principles serve as a reference for describing the solution, which will determine all aspects related to materials, labor, means, and forms of production organization.

The application of the principles that define Low-Carbon Building Technology (LCBT) establishes neither a fixed roadmap to be followed, nor a set of elements to be further added to an existing process. Instead, it is a way of conceiving and designing procedures and methods focused on construction. Another key aspect is LCBT is not a rigid or a static concept in time and space and does not aim to produce standardized or replicable solutions - on the contrary, different social, environmental, economic, and cultural contexts will define unique problems and responses.

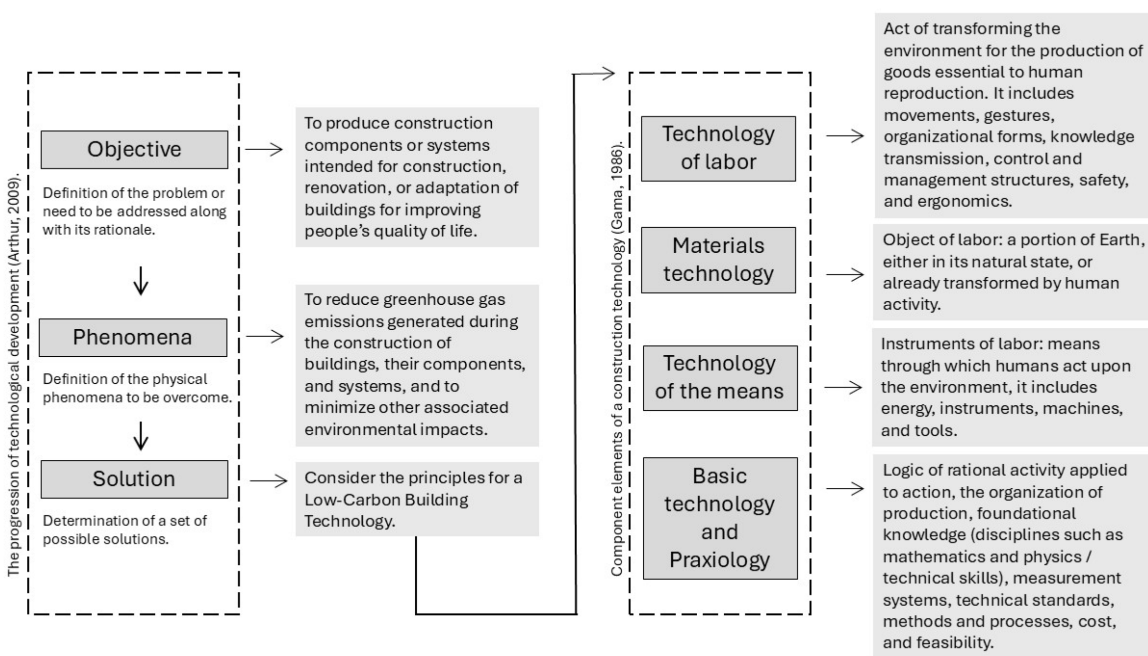

Diagram 1: Relationship between LCBT principles in defining a construction technology.
Source: Elaborated by the authors. Adapted from Arthur (2009) and Gama (1986).

5. CONCLUSIONS

The objective of this article was to propose and discuss the seven principles that characterize Low-Carbon Building Technology, namely, permanent building, unalienated labor, human-nature integration, less energy, self-determination, productive rationality, and popular empowerment, which aim to restructure the way construction technology is decided and defined in building practices.

The development of construction technologies according to those principles is expected to reduce the sector's negative impacts, particularly greenhouse gas (GHG) emissions. Moreover, they will expand their positive impacts by promoting social and territorial development decoupled from the global logic of productivity, increasing social access to the goods necessary for the material reproduction of life through actions that value labor, respect natural cycles, share knowledge, and multiply solutions.

The proposed challenge is huge and does not fall solely on architecture and engineering professionals. It is a socially driven project that demands cultural change and can be fostered through public policy and education. Furthermore, it must involve all actors in the construction sector, including manufacturers of machinery, tools, and materials, design firms, researchers, educational institutions, certification bodies, public authorities, investors, cooperatives and construction companies, financial agents, professional associations, and technology incubators.

The continuation of this research will involve analyses and development of construction technologies based on the proposed conceptual framework towards the understanding of their strengths and weaknesses in practice. Experiences that align with the defined concept must be mapped through examinations of their contexts, conditions, and limitations as an initial test of feasibility and Life Cycle Assessments (LCA) of the selected case studies must be conducted towards the comprehension of their quantitative impact and reflections on characteristics not addressed by the theory. Such investigations will enable revising or adjusting the TCBC framework for making it more coherent and feasible.

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