

## **Inovação e sustentabilidade na indústria da construção: um exercício de ensino no PPG-FAU/UnB**

### **Innovation and sustainability in the construction industry: a teaching exercise in the University of Brasilia's Postgraduate Programme in Architecture and Urbanism**

### **Innovación y sostenibilidad en la industria de la construcción: un ejercicio de enseñanza en el PPGFAU/ UnB (Programa de Posgrado en Arquitectura y Urbanismo)**

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## Resumo

Este artigo apresenta os resultados do desenvolvimento da ferramenta Cais (Concepção e Análise em Inovação e Sustentabilidade) para a estruturação do raciocínio e análise de projetos, concebida e utilizada na disciplina Estudos Especiais em Tecnologia 1: Inovação e Sustentabilidade na Indústria da Construção (PPG-FAU/UnB). O método utilizado foi dividido em fundamentação, concepção, análise e teste de aplicabilidade. O uso do Cais potencializou a estruturação e delimitação das pesquisas, permitiu analisar as contribuições em inovação e sustentabilidade das pesquisas no contexto da CIPC e identificar caminhos para a difusão dos resultados das pesquisas. Essa ferramenta pode ser um instrumento de avaliação, alavancagem e incentivo para projetos que gerem resultados em sinergia com a inovação e sustentabilidade da indústria da construção.

**Palavras-chave:** Estruturação e Difusão de Pesquisas. Inovação. Sustentabilidade. Indústria da Construção.

## Abstract

This paper sets out the results of the development of Cais – Conception and Analysis in Innovation and Sustainability –, a tool to organise the reasoning and analysis of projects, designed and used in the discipline “Specials Studies in Technology 1: Innovation and Sustainability in the Construction Industry” in the University of Brasilia’s Postgraduate Programme in Architecture and Urbanism (PPG-FAU/UnB). The method used was divided into grounding, design, analysis and applicability test. The tool improved the organisation and delimitation of research projects, and enabled the analysis of research contributions to innovation and sustainability in the context of the CIPC. It also helped identify paths to communicate research results. This tool can serve as a device to evaluate, leverage and encourage projects that generate results in synergy with innovation and sustainability in the construction industry.

**Keywords:** Research Organisation and Diffusion. Innovation. Sustainability. Construction Industry.

## Resumen

En este artículo se presentan los resultados del desarrollo de la herramienta CAIS (Diseño y Análisis en Innovación y Sostenibilidad) para estructurar el raciocinio y el análisis de proyectos, creada y utilizada en la asignatura Estudios Especiales en Tecnología 1: Innovación y Sostenibilidad en la Industria de la Construcción (PPGFAU/ UnB). El método utilizado se dividió en: fundamentación, diseño, análisis y pruebas de aplicabilidad. El uso de la CAIS fortaleció la estructuración y delimitación de las investigaciones, permitió analizar las contribuciones en innovación y sostenibilidad de las investigaciones en el contexto de la CIPC e identificar vías para la difusión de los resultados de las investigaciones. Esta herramienta puede ser un instrumento de evaluación, estímulo y motivación para proyectos que generen resultados en sinergia con la innovación y sostenibilidad de la industria de la construcción.

**Palabras clave:** Estructuración y Difusión de Investigaciones. Innovación. Sostenibilidad. Industria de la Construcción.

## Introduction

The construction industry production chain (CIPC) comprises all activities necessary to produce its main product – the built environment – in the form of buildings, spaces and urban infrastructure. The CIPC can be defined as a set of activities articulated in progression, aggregating basic inputs, design intelligence and construction, up to the final product (BLUMENSCHHEIN, 2004).

To apply this concept to the construction industry, Blumenschein (2004) considers three basic industrial groups that are the major links in the CIPC: a. Supply industries, which produce materials, inputs and components; b. Process industries (or main industries), which produce buildings and heavy engineering works; and c. Auxiliary industries, which aggregate architects, consultants, designers, and other professionals who offer design intelligence, planning and production.

Although it is an important vector of economic and social development, this chain causes negative impacts on the environment all along its stages, from the construction to the operation of its main products. In 2011, the CIPC sector Gross Domestic Product (GDP) was R\$ 170.94 billion, 5.35% of the Brazilian GDP (SINDUSCON-SP, 2011).

Despite the economic importance of the CIPC, negative environmental impacts are generated during the entire life cycle of the built environment, from the occupation of land to the demolition and disposal of buildings or infrastructure works, through to the extraction of raw materials, input processing, production of components and derivatives, transportation, construction process, and final product use and operation (BLUMENSCHHEIN, 2004).

The CIPC consumes 40% of raw material and energy, 17% of the world's drinking water, and is responsible for 40% of the volume of solid waste generated in the world. In its third report on the gap between expected and real emissions, the United Nations Environment Programme (UNEP, 2012) points to an increase in emission of greenhouse gases above 70% in the construction sector in the past four decades.

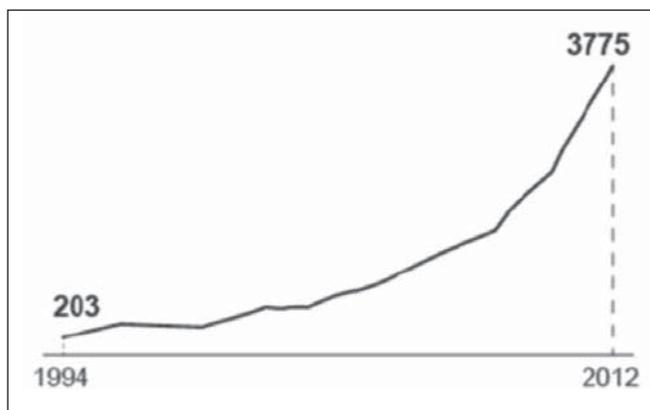
In mid-sized and major Brazilian cities, the rate at which solid waste is generated from construction and demolition can vary from 400 to 700 kg/resident/year. These impacts are exacerbated by the high demand for housing and infrastructure in the country. Brazil has a housing deficit of 7.9 million homes, and a federal government target for the celebration of the country's 200<sup>th</sup> independence anniversary is to zero this deficit by 2022 (TRUSTY; MEIL, 2000; OLIVEIRA; DE OLIVEIRA; FERREIRA, 2008; IPEA, 2011; SAE, 2010).

In addition, the Growth Acceleration Programme (PAC) launched by the government and the international events to be held in the country, such as the 2014 World Cup and the 2016 Olympics, will demand infrastructure works and major buildings. Providing the entire infrastructure to host these major events with international visibility and meeting PAC goals is a challenge that calls for an accelerated shift in technological paradigms so that CIPC processes and products meet sustainability criteria.

According to Blumenschein (2004), a technological paradigm is established along a process of learning accumulation, and therefore depends on knowledge and information accumulated over various production processes, represented by a set of acquired examples. Dosi (1988, p. 224) affirms that a technological paradigm “contextually defines the needs to be met, the scientific principles used for the task and the technological material to be used”.

Accelerating the shift in paradigms towards more sustainable CPIC processes and products becomes urgent if one considers the challenges posed in the 21<sup>st</sup> century, which according to UNEP (2007) include climate change; disasters and conflicts; ecosystem management; environmental governance; hazardous substances; and efficient use of natural resources. Therefore, there is a huge demand for the development and research of knowledge that may contribute to the shift in CIPC technological paradigms.

The last decade saw a significant increase in research focused on the sustainability of the built environment, its production processes and products. A search for technical-scientific production under the theme Sustainability of the Built Environment at the Science Direct website, an international databank of theses, dissertations and articles, demonstrates an increase by 1859% in the number of publications between 1994 and 2012 (Figure 1).



**Figure 1. Survey of the technical-scientific production in Science Direct under the theme Sustainability in the Built Environment.**

Among the obstacles encountered when developing research work are postgraduate students' difficulty in defining the scopes and interfaces of their study subjects; the gap between CIPC real needs in the process of shifting its technological paradigm to cater for society and research work developed in academia; the lack of strategies to disseminate innovative solutions generated in postgraduate programmes; and deficiencies in the definition of objectives and methods, and in the integration of students' research proposals to the research lines developed by advisors.

Among integration difficulties are the lack of a systemic view in the design and development of research works. It is vital to understand the context in which the search occurs, taking into consideration its academic function, its social and economic implications, and the preparation of projects, including the design of strategies to disseminate the knowledge generated.

The objective of this paper is to present the partial results of the development of CAIS – Conception and Analysis in Innovation and Sustainability –, a tool that helps structure the reasoning and analysis of research projects by students and professors. The tool was designed and is being used and improved in the context of the Postgraduate Programme of the School of Architecture and Urbanism at the University of Brasilia (PPGFAU/UnB), in the discipline Special Studies in Technology 1: Innovation and Sustainability in the Construction Industry.

## **Method**

Three steps were taken in the development and application of CAIS:

Step 01 – Reasoning: the contents selected were those that would help students in the development and implementation of the tool. The contents include CIPC concepts, sustainable construction, systemic thinking and innovation theory applied to the construction industry.

Step 02 – Tool design: the identification of the items and criteria to be included in the tool to be built was based on the introduction of the concepts defined in the previous step.

Step 03 - Testing and analysis of the proposed tool: the tool was analysed and used in research by students of the discipline in semesters 02/2011 and 01/2012, and revised according to the results of these analyses.

## **a. Reasoning**

Defining scopes of research and methodological procedures in knowledge production to contribute to the change of paradigms in the CIPC requires one to understand the concepts of sustainability and sustainable construction, and the process of innovation in the construction industry production chain.

### **a.1 Sustainability in the CIPC**

The construction process has considered the triangle cost-quality-term (BLUMENSCHHEIN, 2004) to be competitive factors but the complexity of the chain, the negative environmental impacts and their interference in the environment have forced a change of focus, wherein environmental factors are also considered relevant.

Consequently, the principles that guide the decisions made when adopting construction technologies need to be founded on the concept of sustainability, which considers: conservation objectives, aimed at maintaining ecological processes and ensuring the sustainable use of species and ecosystems, thereby defending the commitment to maintain life (OFQPC, 1992); environmental variables, which are not opposed or parallel to industrial processes, but are part of the whole (HAWKEN et al. , 1999); and the principles of durability, rationalisation and integrated chain management (HENDRIKS, 2000), as well as environmental and social responsibility (MACHADO FILHO, 2002).

According to Blumenschein (2004), three major groups of technological paradigms are relevant for the exercise of implementing guidelines based on sustainability roots:

(I) The first group consists of those who influence and determine decisions in the design phase, who have an impact on the efficiency

of the building operation and includes the project preparation process. These decisions should be based on guidelines such as: (a) integration with the landscape and/or architectural context, with special attention to respecting scales; (b) application of passive design principles, valuing natural lighting and ventilation, and increasing the ability to adapt to the effects of climate change; (c) standardisation of dimensions, elements and components, increasing flexibility in use; (d) reduction of greenhouse gas emissions by committing to specification criteria, guided by the assessment of the life cycle of products; (e) rationalisation of resources; (f) use of water recycling technologies; (g) energy efficiency, prioritising design decisions that will minimise the use of operational energy and reduce energy use, while maintaining adequate levels of lighting and offering greater flexibility to control lighting in occupied areas; (h) and exercising simultaneous projects, ensuring project and technical language compatibility, reducing losses and increasing efficiency by integrating solutions.

(II) The second group is related to the construction process phase and is based on quality management, achieving environmental and social responsibility and on the concept of the construction process as a recycling process. It involves: (a) efficient and responsible management of the construction process; (b) recycling materials and waste; (c) preventive project (applied to buildings, elements and components); (d) responsible purchasing of materials and services; (e) and social responsibility. The continuous exercise of quality management ensures that systems and procedures are introduced throughout the process as a whole, particularly via the implementation of systems and quality programmes, such as ISO or PBQP-H. Consequently, there are fewer errors, less rework, less waste, more quality, more durability and less maintenance, leading to less use of natural resources.

The concept of the construction process seen as a recycling process involves the reintegration of waste generated in construction work as recycled aggregates reintroduced in the production process. Heading to environmental and social responsibility ensures that costs are not transferred improperly and that the company is committed to its employees, the community and society.

(III) The third group refers to extracting and processing raw materials, including supplying materials, elements and components that feed the construction process. In addition, it involves the need to apply the concept of integrated chain management, which involves product life cycle management, considering environmental, social and economic aspects, based on the principle of reducing the use of fossil energy sources and maximising the use of energy sources; in addition to balancing the ecosystem renewal process. It also incorporates the concept of durability, which assumes that materials are extracted and processed, applied and demolished, with the constant concern that they will remain useful and still have quality.

Construction sustainability is related to the durability of the materials used and their ability to resist the weather without losing their original functions (HENDRIKS, 2000). Blumenschein (2004) also says that the durability of a sustainable building is related to the quality of the construction process and the materials used. Hendriks (2000) discusses the flexibility of building as an important premise for sustainability, and Romero (2001) rescues this concept and associates a building's durability to its ability to adapt to its many functions and establish itself as an element of a place's visual identity.

Based on a review of the construction process stages and of the sustainability concepts in the authors' CIPC, an analytical framework was drawn up (Table 1), built by correlating the above-mentioned authors, their concepts and the construction process phases with levels of high, medium or low influence, evidencing that sustainable construction is a concept that covers decision-making through to disassembling the construction.

In the concept of environment-aware constructions as designed by Rovers (2001), for example, there is a high influence on the decision and disassembling edification steps, and a medium influence on the design, construction and use steps, because this concept focuses on the choices made in the process preceding building design, which should consider the use of materials with potential for proper final destination in the disassembling step.

**Table 1. Relationship among authors, concepts and phases of the construction process – levels of influence (high, medium and low).**

Author	Concept	Construction process phases				
		Decision	Project	Construction	Use	Disassembling
Rovers (2001)	Environment-friendly constructions	High	Medium	Medium	Medium	High
	Sustainable constructions	Medium	Medium	High	Low	Low
	Sustainable life	High	Low	Low	Low	Medium
Hendriks (2000)	Flexibility and durability	High	Medium	Medium	Low	High
Romero (2001)	Durability and bio-climatic adaptation	High	Medium	Medium	Low	Low
	Visual identity	High	High	Low	Low	Low

**b. Innovation in the CIPC**

The study of vectors that may cause shifts in CIPC technological paradigms in a sustainable technological path is directly linked to research on innovation processes and technological evolution models applied to the CIPC context (BLUMENSCHHEIN, 2004).

Although model application studies for the analysis of technological change and innovation offer tools that are relevant for the study of innovation and changes in the CIPC, none are fully applicable to this context, particularly in Brazil. First, because they refer to manufacturing industries or (research-intensive) advanced technology industries and most are foreign studies. Second, because the characteristics of the construction’s final product defines peculiarities in its process (TURIN, 1968; IVE; GROAK; 1986). In addition, the number of participants in the construction process strengthens the importance of the social dimension in any analysis (BOWLEY, 1966; IVE; GROAK, 1986; TURIN, 1968). Third, because it is inserted in a country characterised by conflicting realities and disintegrated institutions.

According to Schumpeter (1949), innovation is the use of existing resources in different ways, or still, it is the development of new

combinations of production factors. The concept of new ways of combination includes:

[...] (a) the introduction of a new product; (b) the introduction of a new production method; (c) the opening of a new market; (d) the acquisition of a new source of materials or manufactured products supply; (e) the development of new forms of organisation of any industry, for example, the fall or creation of a monopoly position” (SCHUMPETER, 1939, p. 66 apud BLUMENSCHNEIN, 2004, p. 29).

Freeman and Lundvall (1988), Dosi (1988), Viotti (1997) and Capra (2002) advance the concepts of innovation, and Freeman (1995) makes a difference between Schumpeter's innovation and incremental innovation. Schumpeter's innovation involves shifts in production and markets organisation, and implies primarily the introduction of a new product, process or an “entirely new” form of organisation. Incremental change, in turn, refers to the introduction of improvements to products, processes or production organisation without causing changes to the industry (FREEMAN; LUNDVALL, 1988).

When defining methodological procedures to analyse and evaluate innovation, the Oslo Manual complements this concept by introducing the idea of innovation as the design and implementation of significant changes in product, process, and marketing or in the company's organisation with the purpose of improving results (OECD, 2005).

### **b.1 CIPC vectors of influence**

Blumenschein (2004) stresses the importance of identifying the forces responsible for the appearance of innovations and demonstrating with more depth the relationships between different actors and vectors of influence. In this context, it is necessary to identify the potential vectors capable of influencing the pace of change in CIPC technological paradigms.

The identification of vectors leads to the integration of technical, economic, organisational, institutional and political factors, depending on the regional context or the chain in question, with a highlight to the role

of public policies and the importance of integrating industry coordinating agents (CIB, 1999 apud BLUMENSCHHEIN, 2004).

Considering the environmental crisis in the context of the CIPC, it is fundamental to incorporate and internalise a technological paradigm that is more compatible with ecosystem preservation and the sustainable use of raw materials. In this context, environmental management instruments acquire an important role as vectors of change in production processes.

Still according to Blumenschein (2004), the vectors that influence innovation in the context of the CIPC include those pointed by Schumpeter's theory, as developed by new Schumpeterians:

A) **Market and Demand:** The quest to win markets is a driving force of new products and processes, both in the input supply chain and in the processes chain. As the specific needs of customers are met, new products are introduced in the construction industry;

(B) **Technology and R&D:** the CIPC final product has been radically modified by the insertion of technologies, such as computers, modular components, management techniques, robots, new materials, modern construction methods and others;

(C) **Production:** the integration between constructors and manufacturers leverages the introduction of the vast majority of innovations in the CIPC, because "anyone who uses and applies also learns and improves" (SLAUGHTER, 1993 apud. BLUMENSCHHEIN, 2004, p. 107);

D) **Entrepreneur (leader):** leaders conduct the process of change in the production process of the built environment and have leveraged the emergence of relevant work;

E) **NSI - National Innovation System:** The NSI integrates institutions and instruments structured and designed to overcome weaknesses and strengthen the innovation capabilities of industries. The concept

of NSI, defined by Freeman as “a network of institutions in the public and private sector whose activities and interactions initiate, import, modify or disseminate innovation” (apud VIOTTI, 1997, p. 23), offers an indispensable tool in structuring the analysis and in studying national institutions and their relations in support of the capacity and ability of nations and industries for technological development;

(F) **NLS - National Learning System:** The process of innovation in newly industrialised countries is characterised mainly by absorption and improvements, i.e., by dissemination and incremental changes; therefore, the focus is on continuous learning. This peculiarity led Viotti (1997) to propose a different type of tool. According to him, in lieu of the National Innovation System, the most adequate proposal is to apply the National Learning System (NLS) concept, mainly to analyse the innovation process in countries such as Brazil and Korea, for example. According to Viotti (1997), a learning system is directly linked to standards of education and training, acquisition of technology, resources committed to technological learning and national results in spreading technology;

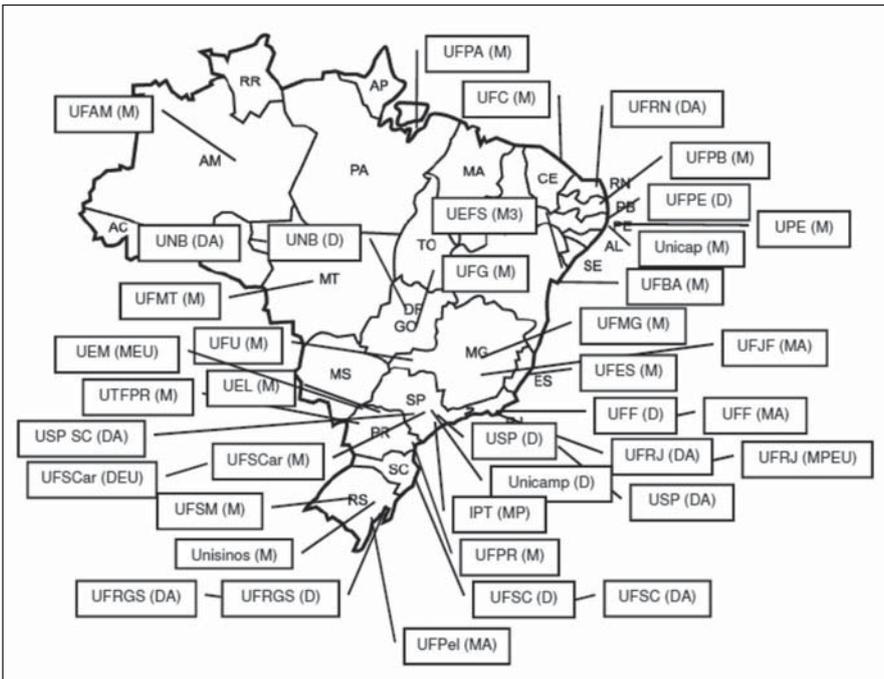
(G) **Environmental Policy Instruments:** The objective of accelerating the uptake of technologies that minimize the impacts caused by the CIPC on the environment makes it necessary to identify the environmental policy instruments that are being used to introduce changes compatible with environmental preservation. The economic innovation theory tends to consider three arguments with respect to the introduction of innovation compatible with the need to preserve the environment: sustainable innovation is induced by changes in prices through taxes or subsidies, by establishing environmental standards or by regulations and codes that encourage or inhibit innovation (OECD, 2005). Three groups of environmental policy instruments have been used: information system, direct regulation and economic instruments (FIORINO, 1995; CAMPOS; CORREA, 1998). This taxonomy is also presented by dividing instruments into coercive (command and control), persuasive and incitative (economic) (BURSZTYN, 1994); and

**(H) Networks - Platforms for the integration of agents, actions and instruments:** Networks enable the sharing of resources, competences and responsibilities, with shared values and objectives as well as interconnection of information. The actors that make up these networks must have common goals and be aware of the importance of working together, sharing responsibilities, actions and resources, because each point of these networks is a centre in potential (MCTI, 2011a). According to Blumenschein (2004), the survival of a network depends on sharing meanings, which then permeate all its levels and function as a leading thread in the interaction processes of parties. These meanings are rooted in beliefs, values and goals, and in the common needs of the actors involved. Johnson (2010) offers an approach that emphasises the complexity of the interconnection of vectors that influence the emergence of innovation. As he presents his analogy using coral banks and beavers as ecosystems engineers that strengthen and promote the survival of organisms, he confirms the importance of collaborative networks.

## **b.2 CIPC innovation in Brazil**

According to Antac (2011), the Technology of the Built Environment area in Brazil is equipped with Research and Development (R&D) infrastructure. A survey conducted by the innovation portal of the Ministry of Science, Technology and Innovation (MCTI) with keywords “civil construction” points to the existence of 10,276 specialists in the area (MCTI, 2011b).

The country has 42 postgraduate centres offering professional master's degree, master's degree and doctorate level programmes in the built environment area, distributed according to Figure 2 (ANTAC, 2011).



Source: Antac, 2011.

**Figure 2. Major postgraduate centres in civil engineering, construction and architecture technology (A) and urban engineering (EU) in Brazil and their levels of qualification (professional master's degree - MP, master's degree - M and master's and doctoral degrees - D).**

One of the innovation milestones in Brazil was Law 10,793 passed in 2004, the Innovation Law, which addresses the need to have legal and efficient tools that contribute to a favourable scenario for scientific and technological development and for stimulus to innovation (BRAZIL, 2004). The creation of a culture of innovation is based on the observation that the production of knowledge and technological innovation increasingly determine policies in developing countries (MCTI, 2011c).

This regulatory framework is organised around three strands: forming an environment conducive to strategic partnerships between universities, technological institutes and businesses; encouraging the participation of science and technology institutions in the innovation process; and encouraging innovation in businesses, according to chapters II, III and IV of Law 10,793 (BRAZIL, 2004).

Among the main vectors of influence in Law 10,793 are the integration of different agents to create research networks and share responsibilities and resources in the development and diffusion of innovation, with contracts or agreements entered into by public administration entities or the private sector. Article 3, sole paragraph, provides that the promotion of research “may contemplate international technological research networks and projects as well as technological entrepreneurship actions and actions to create innovation environments, including incubators and technology centres” (BRAZIL, 2004).

The CIPC strands and production processes should be seen in an integrated way, by understanding its complexity and the role of each actor involved in the process. Considering this premise, the concept of cooperation networks in the CIPC involves agents from the production sectors – public, research and third sector – and their applicability, in addition to revealing itself as an inducer of a shift in paradigms (BLUMENSCHNEIN, 2004; THOMAS, 2011).

### **b. 3 Tool design**

Grounded on the concepts presented previously, the criteria and guiding lines to construct the proposed tool were defined and based on: the systemic understanding of the sustainable construction concept; the concept of innovation, its cycle and vectors with potential to accelerating its pace; and recognition of the importance of designing a strategy that ensures the dissemination of knowledge generated from postgraduate research.

The items and criteria were structured in five blocks (Table 2):

A) **Block 1:** Proposes the characterisation of the research itself and assists with visualisation of the research theme, structuring the project's justification, the hypothesis, the general and specific objectives and expected results. It lays down in a concise fashion the entire scientific research framework that will guide the student throughout the research process;

(B) **Block 2:** Comprises five questions that contextualise the research. The first question identifies the CIPC segment in which the research is contained (supply chain, auxiliary chain or main chain). The second question deals with the type of innovation brought by the research (process, product, marketing or organisational). The third question identifies the demands and needs remedied by the development of the research. The fourth question defines the scientific principles and the last question defines the technological solution proposed or to be sought. It is noteworthy that the first question was included with consideration to the characterisation of the CIPC made by Blumenschein (2004) and the second, with the classifications of innovation made by Schumpeter (1949) and by the Oslo Manual (OECD, 2005). The third question was included to emphasise the importance of research and its relevance to the market. And the two last questions were based on the Theory of Innovation;

(C) **Block 3:** Proposes a survey of agents, actions and instruments, and the relationship of these agents with the research, by forming a cooperation network that defines the responsibilities of each agent in the manufacturing process. The inclusion of this identification matrix was based on the innovation model used by Blumenschein (2004). The interfaces between agents and their impacts are identified in this matrix. Actions are divided according to the innovation development cycle brought by each of the research works: design, development, testing, demonstration and dissemination. The instruments are divided into technical, legal and economic (BURSZTYN, 1994) and should be identified through following the interaction between agent and action;

(D) **Block 4:** Comprises four questions that analyse the research work according to the concepts in the theory of innovation. The questions identify the vectors of influence for the emergence and diffusion of the proposed innovation; the barriers that hinder the diffusion of the innovation, which may be classified as cultural, technical or financial; environmental, economic, social and cultural dimensions, following the classification made by Sachs (2008); and the possible contributions of the research to change the CIPC technological paradigm; and

E) **Block 5:** This is the concluding phase of the tool and proposes the identification of contributions from research to innovation and sustainability in the context of the CIPC. It is assumed that the tool user will need to answer the previous questions to justify what the contributions are.

#### **a. Analysis and application of the tool**

The tool was analysed and used by 14 students of semesters 02/2011 and 01/2012 of discipline EET1: Innovation and Sustainability in the Construction Industry, within PPG-FAU/ UnB, and revised in accordance with the analysis result. After the preparation and implementation of the tool's first version, some questions were found to be missing, while others needed to be reviewed (Table 2).

Adjustments were therefore made by inserting alternatives with objective questions in items 1 and 2 of the second block, identifying what chains are comprised in the CIPC and any types of innovation. Questions 3, 4 and 5 of the second block became more specific in relation to the object of questioning. An introductory text was suggested in block 3 to explain the interface between agents and the use of the terms partial, full and non-existent for the interface, and the terms weak, medium and strong for the impact.

Other dimensions of sustainability were included in the fourth block. In addition, the degree of influence of these dimensions on research had to be considered. Another question was included in this block, covering the areas the research contributes to, considering the environmental impacts caused by the CIPC; and students suggested that an alternative should be left open to allow complementation. In block 5, the question emphasised the need for coherence between the conclusion and the answers presented earlier.

It was suggested that CAIS should be accompanied by a glossary to help understand the terms and fill out the tool. The final tool is available in Table 2.

**Table 2. CAIS tool.**

TITLE OF APPLIED RESEARCH										
Block 1 - The research work										
Justification:										
Hypothesis/question:										
General objective:										
Specific objectives:										
Results expected:										
Block 2 - questions										
1) On what segment does your research CIPC cause impact?										
<input type="checkbox"/> Auxiliary chain <input type="checkbox"/> Main chain <input type="checkbox"/> Supply chain										
2) What type of innovation is in the research? (Justify your answer)										
<input type="checkbox"/> Product innovation <input type="checkbox"/> Process innovation <input type="checkbox"/> Organisational innovation <input type="checkbox"/> Marketing innovation										
3) What are the needs/demands that the research meet in relation to the CIPC segment impacted by your research?										
4) On what scientific principles is the research based?										
5) What is the technological solution to your work?										
Block 3 - Agents, actions and instruments										
On the interface column, please use the terms partial, full or non-existent to categorise the interface between your research and the agents. On the column impact, please use the terms weak, medium and strong to measure the impact caused by your research on the agents listed. The actions and instruments can be marked with an 'X', assessing the agent's presence in the actions phase and what type of instrument is going to influence the participation of that agent in the research. In addition, the agents may be removed, as long as this is justified.										
Leader:										
Research	Interface	Impact	Actions					Instruments		
			Design	Development	Test	Demonstration	Diffusion	Technical	Legal	Economic
Academia										
Production sector										
Public sector										
Media										
Funding agents										
Consumers										
Justificativa dos agentes retirados:										
Block 4: Analysis										
1) What are the vectors of influence that will enable the research to contribute to the CIPC sustainability and innovation?										
2) What are the barriers identified (cultural, technical, financial, etc.)?										
3) What dimensions of sustainability are affected by the research and in what way? Please specify and justify.										
Environmental	<input type="checkbox"/> Highly	<input type="checkbox"/> Average	<input type="checkbox"/> Little	<input type="checkbox"/> Does not apply						
Economic	<input type="checkbox"/> Highly	<input type="checkbox"/> Average	<input type="checkbox"/> Little	<input type="checkbox"/> Does not apply						
National and international	<input type="checkbox"/> Highly	<input type="checkbox"/> Average	<input type="checkbox"/> Little	<input type="checkbox"/> Does not apply						
					Cultural	<input type="checkbox"/> Highly	<input type="checkbox"/> Average	<input type="checkbox"/> Little	<input type="checkbox"/> Does not apply	
					Territorial	<input type="checkbox"/> Highly	<input type="checkbox"/> Average	<input type="checkbox"/> Little	<input type="checkbox"/> Does not apply	
4) What areas did your research contribute to?										
<input type="checkbox"/> Improvement to the construction process; <input type="checkbox"/> Improvement to CIPC used materials; <input type="checkbox"/> Reduced emissions of greenhouse gas; <input type="checkbox"/> Reduced consumption of natural resources; <input type="checkbox"/> Reduced water consumption; <input type="checkbox"/> Reduced generation of construction and demolition residues;										
<input type="checkbox"/> Reduced consumption of energy; <input type="checkbox"/> Waste reduction; <input type="checkbox"/> Promote energy efficiency; <input type="checkbox"/> Water reuse systems; <input type="checkbox"/> Wastewater treatment. <input type="checkbox"/> Complete according to your research.										
5) How can your work contribute to a shift in technological paradigm in the CIPC segment affected by your research?										
Based on your replies, what is the contribution of your research to CIPC innovation and sustainability?										

**b. Results**

Of the 14 students who used CAIS, six were already at a more advanced stage in the definition of their research project, four already had a theme but had not deepened their objectives and methodology, and four did not know what to research.

The tool's evaluation was based on the analyses of results presented by each student in written works and seminars. This evaluation enabled the identification of contributions to research which were made possible with the use of the tool, and the difficulties in applying it. The evaluation result is presented in Table 3.

**Table 3. Use of tool evaluation**

<b>Item evaluated</b>	<b>Result</b>
Contributed to strengthen the systemic view of the construction industry production chain	80%
Helped to define the scope of research	80%
Helped to construct the methodological procedures to develop the proposed research	60%
Enabled the research topic to be better situated in the reality of the built environment production process	80%
Allowed to identify the research contribution to the sustainability of the construction industry production chain	100%
Effective strategies to communicate research results were identified	60%
Integration of public and private sector, academia and third sector agents were considered in the strategies to communicate the research results identified	80%
Found difficulty in the answers posed by the tool without theoretical knowledge it would be very difficult to answer the questions posed by the tool	100%
Considered the objectivity of the questions adequate to the required answers	80%
Considered the structure to complete the form to be adequate	75%
Considered the tool's importance to research development at a level above 8 on a scale of 0 to 10	100%
Judged the questions to be adequate and easily answerable	60%

The 14 students who used the tool were found to be able to look at the contributions in research innovation and sustainability in the context of the CIPC. It is assumed that the knowledge of the concepts that motivated the design of the tool presented in this article are necessary for more coherent and consistent answers, mainly due to the degree of complexity of the CIPC.

Students who are beginning to develop their research project found it more difficult to fill the tool, mainly due to the lack of specific knowledge, theories and terms related to the research. Despite this, completing the tool allowed these students to move ahead in limiting and visualising their research.

In addition, the research works assessed had different foci: product and process. Research works related to product innovation were more easily filled than research involving process innovation.

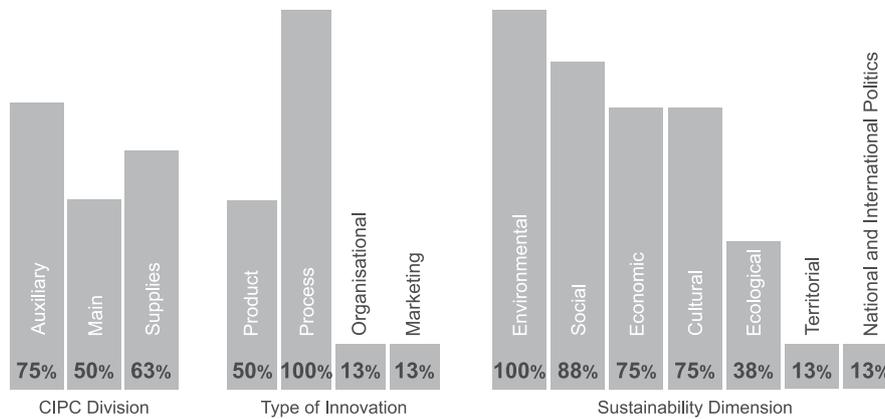
Most of the students managed to develop skills related to systemic vision, scientific methodology, principles of innovation and sustainability concepts. Only 60% of the students managed to identify strategies for the dissemination of their research, which demonstrates a serious deficiency in the dissemination of research results by postgraduate programmes beyond university walls.

The analysis of the CAIS tool applied to research projects showed that 75% of research works were in the CIPC auxiliary chain segment, and these three studies were related to the three CIPC segments. All research projects were related to processes innovation and 50% of them were also related to product innovation.

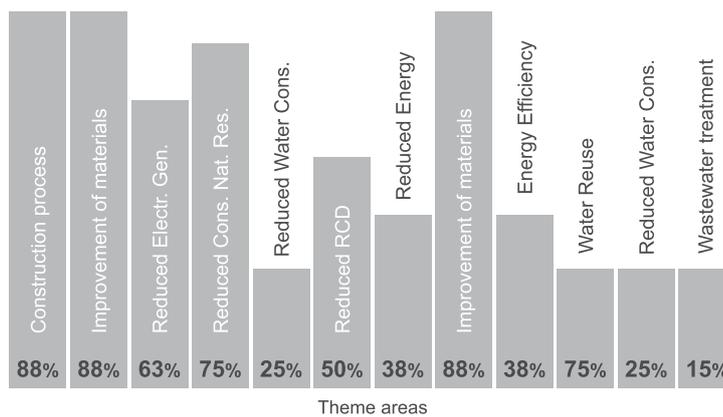
With regard to the sustainability dimensions considered in the tool, all research works were in synergy with the environmental dimension, but only 12% of research works contributed to the territorial and the national and international politics dimensions. The economic, social and cultural dimensions were also in significant synergy, above 75% each.

In the CIPC theme areas defined in the tool which students should mark according to the theme and affinity of their research, 87.5% of research projects contributed to issues related to the improvement of construction processes and the performance of the materials used in the CIPC, but only 25% of research works contributed to reducing water use, to improve water reuse and wastewater treatment. In the energy theme area, 37.5% of research projects contributed to reducing energy use and to improve energy efficiency. In reduction of construction

and demolition waste, 50% of research projects were in synergy, 62.5% contributed to reducing greenhouse gas emissions and 75% were related to the reduction in natural resources use and in materials waste (Figures 3A and 3B). There was no research focusing on the analysis of the CPCI innovation process aiming at defining strategies to accelerate a shift in paradigms.



**Figure 3A. Analysis of students' research results after using the CAIS tool.**



**Figure 3B. Analysis of students' research results after using the CAIS tool.**

Based on the statistics generated, one can observe that the research focus needs to be extended to other segments, such as the CIPC main chain and supplies chain, as well as organisational and marketing innovation. It is necessary to expand research contributions to other sustainability dimensions in addition to the environmental, economic

and social dimensions, and also to address the territorial, ecological, cultural and national and international politics, acting on a more strategic level.

Water-related themes are barely explored by research works, followed by energy and waste from construction and demolition. However, the theme construction processes is greatly relevant in the research analysed because it is a comprehensive theme that involves correlated areas.

### **c. Final considerations**

This paper draws conclusions related to different levels of interaction involving the tool, the method and students' research works; therefore, the final considerations were divided into four blocks: considerations about the teaching method and application of the tool; considerations about the tool's structure and content; considerations about the research delimited by students; and contributions to future work.

In relation to the teaching method used and the use of CAIS on research projects, the teaching method used in discipline EET1: Innovation and Sustainability in the Construction Industry consisting of the tool and lectures, helped students to delimit their research and structure research projects, as well as to start designing the strategy to disseminate the results of their research.

CAIS contributes to structuring the research reasoning, because it helps researchers to substantiate their work more consistently, enabling scientific principles to sustain and maintain the investigation focus. In addition, it offers an opportunity to exercise a systemic view on research and its insertion in the CIPC context and it raises awareness of the importance of identifying strategies for dissemination.

By using the tool, it was possible to observe that it is a useful method to assist students and advisors in structuring research with a focus on innovation, sustainability and dissemination strategies.

Another important contribution was the opportunity students had to participate in the methodology that developed the tool, offering an experience that can assist in the development of other analyses whose objective is the production of similar tools.

Also, the tool developed contributes to its use by the academic community as an evaluation, leverage and encouragement instrument, generating results in synergy with the innovation and sustainability of the CIPC so as to meet the demands of the production and public sector through research developed by academia.

With regard to the content and structure of the tool, the points raised in the five blocks of questions are goals that build a gradual, continuous reasoning that ends with the response to the question about the contributions of innovation and sustainability research. However, the tool's structure needs to be perfected so that any doubts regarding how to fill it are adequate, such as the legends of terms that should be used, whether options must be completed with an 'X' or with a text, whether it is possible to remove or insert options, among others. It is necessary to introduce the identification of incremental innovation, complementing question 2 of Block 2, which surveys the type and the innovation.

With regard to research delimited by students, the application of CAIS was easier for students who had already started their research, but who needed help to view project phases more clearly. Projects related to product innovation were more quickly filled than innovation related to services and processes, because product design tends to be more tangible when compared to services and processes.

Another important point is that all researchers have managed to identify the contributions of their research to innovation and sustainability in the context of the CIPC. With the use of CAIS, the concepts of innovation and sustainability applied to the CIPC have been disseminated, strengthening the understanding that it is not possible to think of innovation without considering the concept of sustainability, since they are criteria connected and intrinsic to economic, social and environmental development.

CAIS is above all qualitative, and is in the process of being developed. In future works, we believe that the use of the tool by students from other PPG-FAU classes can contribute to its improvement, and to include quantification mechanisms to measure the degree of sustainability and innovation of each research work, with a view to reducing the subjectivity of the analysis.

Another supplement to the tool is a glossary to make the filling task clearer, easier and more autonomous for students. It is also necessary to create a questionnaire that systematises the evaluation of CAIS by students, assigning scores to selected criteria related to the content, structure, objectivity and the degree of importance of the tool for the definition and delimitation of research projects.

This tool can also be adapted to other areas of research in which the shortage of innovation and sustainability projects can be mitigated with the insertion of a mechanism to structure the reasoning and analysis of research projects, such as CAIS.

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