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Digitalization and Energy Efficiency in the Building Sector in Brazil

Potential for 2050: Assumptions and Scenarios

Por meio da

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Content

Glossary

°C	Degree Celsius
ABNT	Brazilian Association of Technical Standards
AI	Artificial Intelligence
ANATEL	National Telecommunications Agency
ANEEL	National Agency of Electric Energy
BIM	Building Information Modeling
BMS	Building Management Systems
BMWK	German Federal Ministry for Economic Affairs and Climate Action
BNDES	National Bank for Economic and Social Development
CCEE	Electric Energy Trading Chamber
CGIEE	Energy Efficiency Indicators and Levels Managing Committee
CIM	Interministerial Committee on Climate Change
CIM	Electricity Sector Modernization Implementation Committee
CO_2	Carbon Dioxide
CONPET	National Program for Rationalizing the Use of Oil and Natural Gas Derivatives
COP21	Conference of the Parties 2021
EBC-TCP	Energy Technology Collaboration Program in Buildings and Communities
EESUD	Energy Efficiency for Sustainable Urban Development
EPE	Energy Research Office
ESG	Environmental, Social, and Governance
FGEnergia	Guarantee Fund for Energy Efficiency Credit
FGV	Getúlio Vargas Foundation
FNDCI	National Fund for the Development of Smart Cities
GDP	Gross Domestic Product
GEM	Global Entrepreneurship Monitor
GHG	Greenhouse Gases
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit* (German Cooperation for Sustainable Development)
HVAC	Heating, Ventilation and Air Conditioning
IBGE	Brazilian Institute of Geography and Statistics
IEA	International Energy Agency
INI-C	Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Service and Public Buildings
Inmetro	National Institute of Metrology, Quality and Technology
IoT	Internet of Things
IPCA	National Consumer Price Index
kWh	Kilowatt-hour
LC/NC	Low-Code/No-Code
LGPD	General Personal Data Protection Law
MCID	Ministry of Cities
MCTI	Ministry of Science, Technology and Innovations
MDR	Ministry of Regional Development
ME	Ministry of Economy
MME	Ministry of Mines and Energy
MWh	Megawatt-hour
NDC	Nationally Determined Contribution
NECL	National Energy Conservation Label
OCP	Product Certification Bodies
ONU	United Nations
ONS	National Electric System Operator
p.	page
PBE	Brazilian Labeling Program
PBQP-H	Brazilian Habitat Quality and Productivity Program

PCVA Green and Yellow House Program

PDEf Ten-Year Energy Efficiency Plan

PECS Customized Environmental Control Systems

PEE Energy Efficiency Program

PMCMV Minha Casa Minha Vida Program

PNCI National Smart Cities Policy

PNMC National Policy on Climate Change

PPH Possession and Habits Research

PPT Public Policy on Telecommunications

PROCEL National Electric Energy Conservation Program

PSQ Sectorial Quality Program

R$ Reais (Brazilian currency)

R&D+I Research, Development, and Innovation

RAC Conformity Assessment Requirements

RTQ-C Technical Quality Requirements for the Energy Efficiency Level of Commercial, Utility, and Public Buildings

RTQ-R Technical Quality Regulation for the Energy Efficiency Level of Residential Buildings

S&T Science and Technology

SDG Sustainable Development Goals

Sebrae Brazilian Micro and Small Business Support Service

SiAC Services and Works Conformity Assessment System

SiMAC Qualification System for Materials, Components and Construction Systems Companies

SiNAT National System of Technical Evaluations of Innovative Products and Conventional Systems

tCO_2 Tons of CO_2

TWh Terawatt-hour

UNFCCC United Nations Framework Convention on Climate Change

WG Working Group

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Executive summary

The building sector accounts for about 1/6 of the energy consumption and 50% of the electricity consumption in Brazil. It is a complex sector with several actors and of great economic importance for the country. Currently, the degree of digitalization in this sector is still low, especially due to the high investment costs and the difficulty of estimating the benefits provided by digital technologies.

Digital solutions in buildings have been applied fundamentally in commercial buildings and corporate profile services. The potential contribution of digitalization to the increase of energy efficiency in the building sector in Brazil is pointed out as relevant in the sector context in the medium- and long-term horizons.

In order to contribute to the debate on the possible evolutionary trajectories of the conditioning factors of digitalization in the building sector in the medium and long term and to subsidize the formulation or revision of public policies, decisions and actions of the present, three prospective scenarios were constructed regarding the potential of energy efficiency resulting from digitalization in the building sector in Brazil, in the 2050 horizon. As the main result of this prospective study, the scenarios have outlined paths for alternative futures of digitalization, recommended according to three implementation rhythms – slow, moderate or fast. In summary, the three scenarios are:

Scenario A – Slow digitalization: Digitalization in the building sector in Brazil occurs at a slow pace, with induction by the State limited to public buildings. Public housing policies emphasize housing of social interest (HIS). The use of digital solutions in HIS and the potential increase in energy efficiency are considered aspects of lesser relevance in view of the pressing need to reduce the housing deficit.

The adoption of some digital solutions, implemented in the design, construction, operation and renovation phases of buildings, occurs autonomously, following the natural evolution of the market for these technologies in the country. The mapping of the implementation of these solutions by life cycle phase in this scenario can be seen in Picture 2.9.

As a result of the slow pace of digitalization in the sector, the potential for energy efficiency is low, at levels below 10% of the total of 161 TWh by 2050[1], comparable to the annual electricity consumption of up to about 840 thousand households[2], and equivalent to avoided emissions[3] of about 200,000 tCO_2.

Scenario B – Moderate digitalization: Digitalization in the building sector in Brazil is implemented at a moderate pace, being induced by the State in public, commercial and service buildings, through regulatory instruments for digitalization and energy efficiency. Public housing policies include mechanisms aimed at increasing energy efficiency and digitalization in housing of social interest, with emphasis on digital technologies of transversal application. Digital solutions are implemented at all phases of the life cycle of buildings, with the increasing participation of private investments.

[1] In the “Expansion Challenge” scenario of the 2050 National Energy Plan, an energy efficiency potential of 321 TWh is estimated in Brazil, which corresponds to 17% of the total electricity consumption in the considered horizon (2050). Given that the building sector is currently responsible for around 50% of total electricity consumption in Brazil, it is estimated that the potential for energy efficiency in the building sector will be around 161 TWh by 2050. The bases for estimating the percentage of energy efficiency potential in the slow digitalization scenario are described in Chapter 2 (section 2.7 – item 2.7.3).

[2] Calculated based on the average monthly electricity consumption per household presented in the 2019 Residential Class Ownership and Habits of Use Survey [75] (see section 2.7 – item 2.7.3).

[3] Calculated from the average CO2 equivalent emission factor available on the website of the Ministry of Science, Technology and Innovations for the year 2021 [76]. This factor aims to estimate the equivalent CO2 emission associated with a given electricity generation (section 2.7 – item 2.7.3).

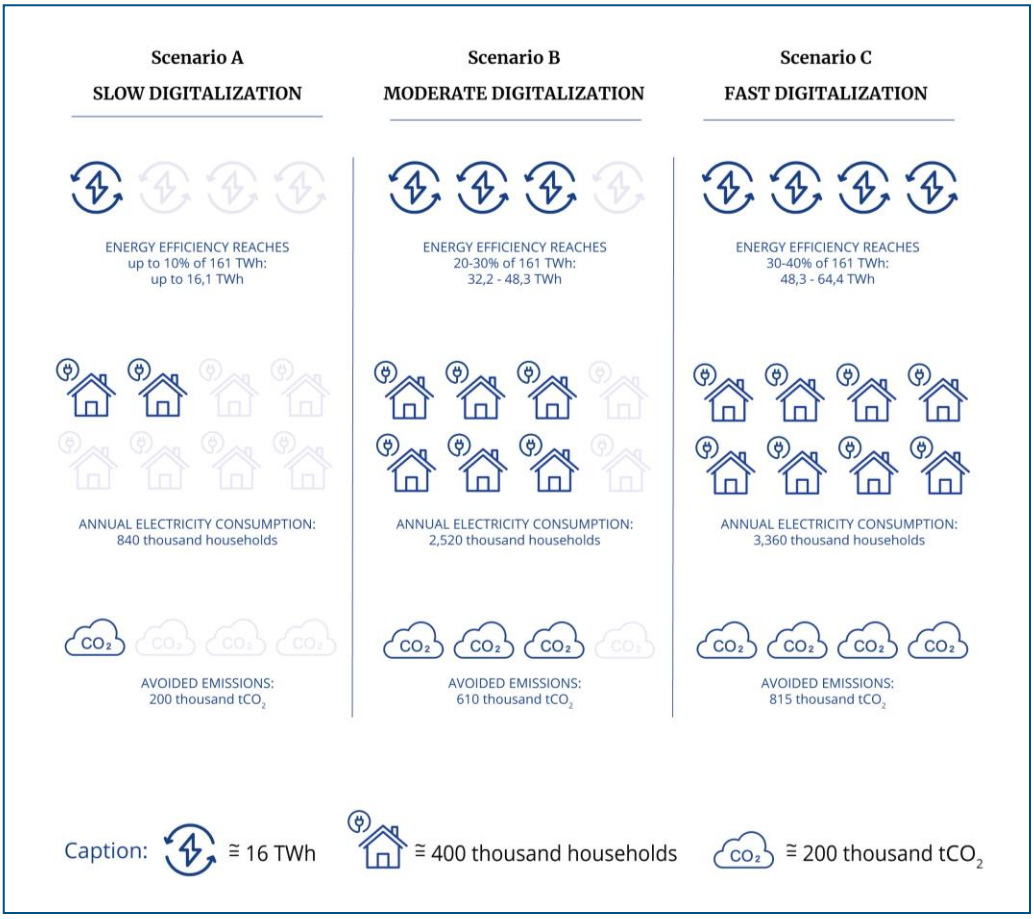
The mapping of the implementation of these solutions by life cycle phase in this scenario can be seen in Picture 2.10.

The energy efficiency potential resulting from moderate digitalization reaches levels of 20 to 30% of the total of 161 TWh by 2050[4], comparable to the annual electricity consumption of up to about 2,520 thousand households[5], and equivalent to avoided emissions[6] of about 610 thousand tCO_2.

Scenario C – Fast digitalization: Digitalization in the building sector is implemented at a rapid pace in the country, being strongly induced by the State, with broad participation of private investments and accelerated adoption of digital technologies. It covers all types of buildings, due to the effective integration between the various institutional and regulatory mechanisms aimed at digitalization, energy efficiency and housing.

Many commercially available digital solutions are adopted at all phases of the building life cycle as early as the first decade. With the rapid digitalization in the building sector, there is a widespread use of digital technologies, driven by the country's economic growth, increased public and private investments, and the integration of public policies and instruments aimed at energy efficiency, housing, and digitalization. Commercially available digital solutions are adopted at all phases of the life cycle of buildings from the first decade. The mapping of the implementation of these solutions by life cycle phase in this scenario can be seen in Picture 2.11.

The energy efficiency potential, resulting from rapid digitalization, reaches levels of 30 to 40% of the total 161 TWh by 2050[7], comparable to the annual electricity consumption of up to around 3,360 thousand households[8], and equivalent to avoided emissions[9] of about 815 thousand tCO_2.



Picture 1 – Energy efficiency potential for each digitalization scenario, as a percentage of the total of 161 TWh by 2050. **Source: Made by the authors.**

[4] See footnote 1. The basis for estimating the percentage of energy efficiency potential in the moderate digitalization scenario are described in Chapter 2 (section 2.7 – item 2.7.3).

[5] See footnote 2 (section 2.7 – item 2.7.3).

[6] See footnote 3 (section 2.7 – item 2.7.3).

Actors, stakeholders, and influencers of the digitalization scenarios in the building sector

We tried to understand the power of interested actors and influencers on the issue in focus, by their performance and influence on the key variables, particularly driving forces of the evolution of digitalization in the building sector in Brazil, in the 2050 horizon. The results of this analysis indicated that the Ministry of Mines and Energy (MME), the Ministry of Economy (ME) and the Ministry of Regional Development (MDR) constitute the most important actors due to their great capacity to influence the increase of energy efficiency in the building sector, resulting from digitalization in this sector.

At a second level are the regulatory agencies (ANATEL and ANEEL), the financial agents (BNDES, Caixa Econômica, public and private banks) and bodies of the Municipal Public Administration. Companies in the production chain of the building sector also have a prominent position in the hierarchy, especially construction and developers, architectural, engineering and consulting offices, as well as building managers and suppliers of materials and electronic equipment.

No less important in the hierarchy are the actors who act on key link variables, such as:

- **i.** Standardization and certification bodies acting on the variable “Technical standardization and regulation applicable to digitalization in the building sector”;
- **ii.** Universities, technical schools, research centers, startups and accelerators influencing the evolution of the variable “Multilevel training in digital solutions for professionals in the building sector”;
- **iii.** Third sector organizations with an interest in energy efficiency and digitalization, influencing the behavior of building users;
- **iv.** Users, for the component of awareness of energy efficiency and the benefits of using digital solutions in their daily lives.

Constraints of digitalization in the building sector

The identification and classification of the key variables by structural analysis allowed the analysis and selection of the conditioning factors of the future, that is, those relevant phenomena that will shape the evolution of the most probable scenarios of the energy efficiency potential of buildings in Brazil, resulting from digitalization in the sector in focus.

Based on the analysis of the current situation (2021), the team's experience and the results of the semi-structured interviews conducted with specialists (Appendix 1), 22 constraints of the future were identified, eleven political-regulatory and eleven non-regulatory (Chapter 2 – section 2.6). To illustrate, the following are mentioned:

- **i.** Integration of public policies and energy efficiency mechanisms and continuity of the National Electric Energy Conservation Program (PROCEL) and the Brazilian Building Labeling Program (BLP Edifica);
- **ii.** Implementation of the National Climate Change Policy (PNMC) and the Nationally Determined Contribution (NDC);
- **iii.** Revision of the National Housing Plan with expected validity until 2040 (PlanHAB 2040);
- **iv.** Implementation of the National Strategy for the Dissemination of BIM in Brazil;
- **v.** Technological development and offer of digital solutions in the country.

Case studies prove increased energy efficiency resulting from digitalization

In addition to the scenarios, the impact of digital solutions on increasing energy efficiency was evaluated based on the analysis of four digitalization case studies in buildings of different types and at different phases of the life cycle, namely:

- **i.** Minha Casa + Sustentável (Rio de Janeiro – RJ) – project phase;
- **ii.** AQWA Corporate (Rio de Janeiro – RJ) – design and operation phases;
- **iii.** São Paulo Corporate Towers (São Paulo – SP) – design and operation phases;
- **iv.** Gávea Planetarium (Rio de Janeiro – RJ) – renovation and operation phases.

Research and analysis of cases of adoption of digital solutions in buildings in Brazil show that, even though there are important examples, the degree of digitalization in buildings in Brazil is still low, compared to the number of projects in the national territory. It can also be seen that the information associated with the cases is not adequately computed and disseminated, incurring the difficulty of obtaining energy saving data or of segregating the energy efficiency values derived from improvement measures derived from digitalization (notably those implemented since the origin of the building, due to the lack of well-defined parameters).

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[7] See footnote 1. The bases for estimating the percentage of the energy efficiency potential in the rapid digitalization scenario are described in Chapter 2 (section 2.7 – item 2.7.3).

[8] See footnote 2 (section 2.7 – item 2.7.3).

[9] See footnote 3 (section 2.7 – item 2.7.3).

Barriers to digitalization, strategic implications, and recommendations

At the end of Chapter 2, the results of the analysis of the barriers to the implementation of digitalization in the building sector in Brazil and the strategic implications are presented. Based on document analysis and semi-structured interviews conducted with experts during the month of November 2021 (Appendix 1), the team identified a set of barriers, which were later classified into four groupings, as listed below.

Institutional barriers (IB)

- Implementation of the various sectoral public policies in an uncoordinated manner, without synergy between the competent bodies (IB1);
- Retraction of investments in CT&I with an impact on the digitalization of sectors of the economy (IB2);
- Standardization and regulatory processes do not keep pace with the evolution of digital technologies (IB3);
- Some of the representatives of the building sector in Brazil resist norms and regulations and their applications (IB4).

Market and financial barriers (MB)

- Lack of specific credit lines for the implementation of digital solutions in buildings (MB1);
- High initial costs of adopting technological solutions in buildings by pioneers (MB2);
- Low purchasing power of users of some typologies for the adoption of digital solutions (MB3);
- Low availability of information on the potential and costs of energy efficiency opportunities (MB4);
- Opportunity costs (need for reforms) not used for reforms focusing on energy efficiency and digitalization (MB5);
- Impact of the costs of implementing digitalization in Social Interest Housing (HIS) (MB6);
- Lack of precise definition of roles and responsibilities regarding the use and warranty of equipment incorporated into the building (MB7).

Technical barriers (TB)

- Uneasy interfaces hindering the adoption of digital solutions (TB1);
- Lack of internet infrastructure to provide wide and quality access for the promotion of digitalization in buildings (TB2);
- Embryonic internship in the country of standardization of processes, materials and equipment in the building sector (TB3);
- Cybernetic insecurity (TB4);
- Adoption of digitalization in existing homes and small businesses/services, as it requires civil works, may make its implementation unfeasible (TB5).

Behavioral and qualification barriers of skilled labor (BB)

- Resistance of the construction sector to new digital technologies in buildings (BB1);
- Low user confidence regarding the benefits of adopting digital solutions and cybersecurity (BB2);
- Culture of energy efficiency in Brazilian society (BB3);
- Curricula outdated in vocational courses and higher education in relation to the topics digitalization and energy efficiency (BB4);
- Low supply of professional education and training in building digitalization (BB5);
- Rapid technological changes make it difficult for the market to keep up to date (BB6);
- Greenwashing of buildings (BB7).

Seeking to contribute to the formulation of public policies and actions aimed at digitalization and energy efficiency in the building sector in Brazil and reduce risks in decision-making processes, both in the public and private spheres, a set of recommendations associated with barriers is proposed in Chapter 4 institutional (IB); marketing and financial (MB); technical (TB); and behavioral and qualification of specialized labor (BB) (Tables 1 to 4).

Table 1 – Recommendations associated with institutional barriers IB1 to IB4. **Source: Made by the authors.**

Recommendation	Barrier
RIB1 – Revise the institutional framework for energy efficiency: • Establish governance that ensures coordination between various sectoral policies (housing, transportation, CT&I, education, environment, health, industry, energy, etc.); • Establish and publish long-term agenda for the application of program resources such as PROCEL and PEE/ANEEL but not restricted to them in a context of greater institutional coordination and integration of energy efficiency initiatives; • Reinforce the role of the MME and MDR in the sectoral coordination of policies aimed at promoting energy efficiency in the building sector.	**IB1**
RIB2 – Develop a joint plan with the participation of government agencies, public and private institutions and the third sector to promote digitalization in the building sector, with a view to exploring synergies and integrating policy instruments under the control of different bodies.	**IB1**
RIB3 – Create public-private funds to support innovation, in the form of non-refundable funds for crowdfunding, matchfunding, equity funds, among others.	**IB2**
RIB4 – Develop programs/services in niches with greater space for national technological development, focusing on digital solutions for energy efficiency in buildings (mission-oriented).	**IB2**
RIB5 – Direct the efforts of S&T institutions and companies to the development of digital solutions applicable to buildings, adopting the model of technological platforms, among other possibilities, under the coordination of the MCTI and support of the MME, MDR and ME.	**IB2**
RIB6 – Strengthen technical cooperation MDR - ABNT, with the scope extended to other competent government sectors, class entities and S&T institutions, to accelerate the process of creating, updating and publishing Brazilian standards.	**IB3**
RIB7 – Create instruments to encourage Brazil's participation in international digitalization standardization forums.	**IB3**
RIB8 – Develop and disseminate success stories of increasing productivity and energy efficiency with the use of digital solutions in buildings, by type and phase of the life cycle.	**IB4**
RIB9 – Create international technological and commercial exchange programs, mainly with leading countries in digital solutions applicable to buildings and aimed at companies in the construction sector and the building sector.	**IB4**
RIB10 – Include the theme of digitalization as a tool for leveraging energy efficiency in the existing discussion forums of the building production sector.	**IB4**

Caption: IB1 – Implementation of the various sectoral public policies in an uncoordinated manner, without synergy between the competent bodies.
IB2 – Retraction of investments in CT&I with an impact on the digitalization of sectors of the economy.
IB3 – Standardization and regulation processes do not keep up with the pace of evolution of digital technologies.
IB4 – Some of the representatives of the building sector in Brazil resist rules and regulations and their applications.

Table 2 – Recommendations associated with market and financial barriers MB1 to MB7. Source: Made by the authors.

Recommendation	Barrier
RMB1 – Improve taxation for the civil construction sector and the building sector and create financing mechanisms under differentiated conditions for the development and adoption of applicable digital solutions.	**MB1** **MB6**
RMB2 – Create specific credit lines by associating digital technologies with efficient buildings.	**MB1** **MB6**
RMB3 – Incorporate digital solutions (mainly IoT) in the white line of home appliances, making it possible to include them in rebate programs and in the PEE ANEEL.	**MB1** **MB6**
RMB4 – Encourage voluntary DEO Certification, through programs such as specific credit lines.	**MB1** **MB4**
RMB5 – Create programs for the development of suppliers of goods and services related to digital technologies for the building sector.	**MB2**
RMB6 – Promote the insertion of smart sockets to control electricity consumption in the financing of social interest housing (HIS), through a white tariff and support for demand response.	**MB3**
RMB7 – Create and keep up to date an Integrated Energy Efficiency Information System in Brazil, for a user-friendly interface aiming at interaction with stakeholders and back office with discretized databases (including data from the building sector segregated by type and phase of life cycle).	**MB4**
RMB8 – Make mandatory the labeling of new constructions and renovations of commercial, residential and public buildings in a scheduled, planned and transparent manner, with minimum levels specified by typology and by phase of the life cycle, aiming at the mandatory of all new buildings and renovations, in the market formal, in obtaining the "A" level of the PBE Edifica after 2035.	**MB4**
RMB9 – Update benchmarks for the most representative building typologies in the market, in quantitative terms and intensity of energy use, preferably through a single interface for dissemination.	**MB4**
RMB10 – Regulate Energy Performance Certification of Buildings in Operation (DEO) and automatic recertifications, based on data from smart meters and based on remote models for auditing and opening energy information.	**MB4**
RMB11 – Make mandatory the DEO certification by typology in a scheduled, planned and transparent manner, with specified minimum levels.	**MB4**
RMB12 – Encourage, through regulatory incentives (or specific credit lines), the adoption of cutting-edge technological and digital solutions in building renovations to take advantage of opportunity costs.	**MB5**
RMB13 – Promote the creation by municipalities of market incentives such as the onerous granting of the right to build for the implementation of digital solutions for energy efficiency in buildings.	**MB2**
RMB14 – Create specific R&D+I projects related to the digitalization of buildings, with a view to energy efficiency.	**MB2** **MB4**
RMB15 – Establish specific standardization for measuring and evaluating the performance of equipment integrated into buildings, as well as roles and responsibilities regarding its use and warranty.	**MB7**
RMB16 – Foster the insurance and reinsurance market related to the digitalization of buildings.	**MB7**

Caption: MB1 – Lack of specific credit lines for the implementation of digital solutions in buildings.

MB2 – Initial high costs of adopting technological solutions in buildings by a pioneer.

MB3 – Low purchasing power of users of some types for the adoption of digital solutions.

MB4 – Low availability of information on the potential and costs of energy efficiency opportunities.

MB5 – Opportunity costs (renovation need) is not used, for instance, with a focus on the energy efficiency and digitalization.

MB6 – Opportunity costs (need for reforms) not used for reforms focusing on energy efficiency and digitalization. BM6 – Impact of the costs of implementing digitalization in Social Interest Housing (HIS).

MB7 – Lack of precise definition of roles and responsibilities regarding the use and warranty of equipment incorporated into the building.

Table 3 – Recommendations associated with technical barriers TB1 to TB5. **Source: Made by the authors.**

Recommendation	Barrier
RTB1 – Adopt an international approach related to technical regulation to minimize any negative effects related to the lack of interoperability between digital solutions.	**TB1**
RTB2 – Promote the development of human-centered digital solutions applicable to buildings.	**TB1**
RTB3 – Enable investments in telecommunication (internet) infrastructure, mainly focused on broadband and mobile network, with a view to expanding adequate access to digitalization.	**TB2**
RTB4 – Strengthen mechanisms and programs for the standardization of materials and services in civil construction.	**TB3**
RTB5 – Propose standardization regarding appliances and other equipment with embedded intelligence.	**TB3**
RTB6 – Propose standardization related to the Internet of Things (IoT) in its applications in buildings.	**TB3**
RTB7 – Adopt cybersecurity standards to minimize the number of cyber attacks, as well as adequate legislation to prevent and respond to incidents.	**TB4**
RTB8 – Promote funding in S&T institutions for the development of the Internet of Things (IoT).	**TB3**
RTB9 – Promote the development of fully Wi-Fi devices to be connected to non-intelligent electronic/electrical equipment from the factory, avoiding infrastructure works and the need to exchange (before the end of its useful life) for intelligent equipment.	**TB5**

Caption: TB1 – Non-friendly interfaces hindering the adoption of digital solutions.

TB2 – Lack of internet infrastructure to provide wide and quality access for the promotion of digitalization in buildings.

TB3 – Embryonic stage in the country of standardization of processes, materials and equipment in the building sector.

TB4 – Cyber insecurity.

TB5 – Adoption of digitalization in existing homes and small businesses/services, as it requires civil works, may make its implementation unfeasible.

Table 4 – Recommendations associated with behavioral and skilled labor qualification barriers BB1 to BB7.
Source: Made by the authors.

Recommendation	Barrier
RBB1 – Establish a specific integrated communication plan for each public interested in building digitalization and energy efficiency in the country, emphasizing: • Not only financial but also climatic benefits (reduction of GHG emissions); • Possibility of empowering the management of energy consumption by the user; • Mapping digital technologies for each target audience; • Awareness for protection against greenwashing practices in the building sector.	**BB1** **BB2** **BB3** **BB7**
RBB2 – Create or reformulate curricula in vocational and higher education courses in relation to the topics of digitalization and energy efficiency.	**BB4** **BB5**
RBB3 – Develop a continuous training plan for professionals providing services associated with digitalization in buildings, emphasizing the clear delimitation of the scope of training, so as not to be too broad. An example would be a course focusing on each of the domains covered in this study.	**BB5**
RBB4 – Encourage technological skills programs in companies operating in the building sector.	**BB5**
RBB5 – Implement measures that allow a transition time to adapt the market to digitalization in the building sector.	**BB6**
RBB6 – Implement measures to curb greenwashing practices in the building sector, including: • Complaints to consumer protection agencies; • Exhibition/disclosure of greenwashing cases in buildings; • Homogenization of ESG parameters for companies in the building sector to build a robust and reliable evaluation framework.	**BB7**

Caption: BB1 – Resistance of the construction sector to new digital technologies in buildings.
BB2 – Low user confidence regarding the benefits of adopting digital solutions and cybersecurity.
BB3 – Culture of energy efficiency in Brazilian society.
BB4 – Outdated curricula in vocational courses and higher education in relation to the topics of digitalization and energy efficiency.
BB5 – Low supply of professional education and training in building digitalization.
BB6 – Rapid technological changes make it difficult for the market to keep up to date.
BB7 – Greenwashing of buildings.

1. Introduction

The digital transformation in the building sector, as in all other sectors of the economy, is becoming increasingly present in everyday life by enabling the collection, storage, organization and processing of data in an unprecedented way. The available data set can be analyzed and related to specific contexts, generating useful information for the systematization of processes in an increasingly optimized way.

Digital transformation can also make the integration of buildings into urban systems and their interaction with each other more efficient. Smart buildings can use the potential for load shifting for efficient integration of renewable energy systems. Among the main functions to which digitalization can contribute in this sector, energy efficiency stands out for the purpose of this study.

The building sector accounts for about 1/6 of the energy consumption and 50% of the electricity consumption in Brazil. This sector presents major challenges for the energy sector associated with more efficient choices between local and centralized generation, digitalization of electricity distribution networks and expansion of natural gas distribution networks [1]. Other challenges relate to the creation of environments conducive to the adoption of digital technologies throughout the life cycle of buildings, educational actions to make society aware of the benefits of energy efficiency and digitalization for efficient buildings, and an adequate economic-regulatory framework. Such challenges require institutional articulation between the various social actors so that the energy needs of the building sector can be met more effectively.

In this study, twenty digital solutions were analyzed that can contribute to energy efficiency throughout the life cycle of a building. These solutions included: management and automation technologies; modeling, simulation and evaluation computer programs; data management and security technologies, technologies that increase productivity, and Building Information Modeling (BIM) technology. The design phase is important because several parameters of the building can be defined in the design and determine the energy performance of the building by years (solar orientation, ventilation systems, envelope, among others). New developments in the field of digitalization (e.g., the Building Information Modeling – BIM methodology) may define the course to improve the energy efficiency of buildings of various types. In addition, the digitalization of construction processes can drive the standardization of components and construction processes associated with measures of energy efficiency to be adopted on a large scale at a more affordable cost, including for social housing (HIS).

Today, the degree of digitalization in the building sector in Brazil is still low, especially due to the high investment costs and the difficulty of estimating the benefits provided by digital technologies in this sector. Digital solutions in buildings have been applied fundamentally in commercial buildings and corporate profile services but there are case studies conducted mainly by the academy, which are directed to HIS [2].

The present study was prepared within the scope of the Brazil-Germany Energy Partnership and the Energy Efficiency for Sustainable Urban Development (EESUD) project and aims to meet the demand of the Technical Group for Energy Efficiency in Buildings (WG-Edificações), linked to the Steering Committee of Energy Efficiency Indicators and Levels (CGIEE) of the Ministry of Mines and Energy (MME), regarding the role and potential of digital technologies associated with energy efficiency in the building sector at the national level.

The objective of the study is to identify and systematize digital solutions and applications for residential, commercial and public buildings, in relation to different market sectors and considering the entire life cycle of the building, in order to provide a basis for the formulation of public policies aimed at increasing the energy efficiency of the building sector, through digital transformation. To achieve this general objective, a methodology was devised in three phases: exploratory-descriptive, prospective, and purposeful. This final report refers to the last two phases. The results of the first phase were presented in the preliminary study report [2].

The potential contribution of digitalization to increase energy efficiency in the building sector in Brazil is pointed out as relevant in this sectoral context in medium- and long-term horizons, as advocated by the three prospective scenarios presented in this document.

In order to contribute to the debate on the possible evolutionary trajectories of the conditions of digitalization in the building sector in the medium and long term and to subsidize the formulation or review of public policies, decisions and actions of the present, this report anticipates three prospective scenarios referring to potential for energy efficiency resulting from digitalization in the building sector in Brazil, in the horizon 2050. The scenarios outline paths for alternative digitalization futures, recommended according to three implementation rhythms – slow, moderate or fast. The following is a brief description of each scenario.

Scenario A – Slow digitalization: Digitalization in the building sector in Brazil occurs at a slow pace, with induction by the State limited to public buildings. Public housing policies emphasize housing of social interest. The use of digital solutions in HIS and the potential increase in energy efficiency are considered aspects of lesser relevance in view of the pressing need to reduce the housing deficit. The adoption of some digital solutions, implemented in the design, construction, operation and renovation phases of buildings, occurs autonomously following the natural evolution of the market for these technologies in the country.

As a result of the slow pace of digitalization in the sector, the potential for energy efficiency is low, at levels below 10% of the total 161 TWh by 2050[10].

Scenario B – Moderate digitalization: Digitalization in the building sector in Brazil is implemented at a moderate pace, being induced by the State in public, commercial and service buildings, through regulatory instruments for digitalization and energy efficiency. Public housing policies include mechanisms aimed at increasing energy efficiency and digitalization in housing of social interest, with emphasis on digital technologies of transversal application. Digital solutions are implemented at all phases of the life cycle of buildings, with the increasing participation of private investments. The energy efficiency potential resulting from moderate digitalization reaches levels of 20 to 30% of the total 161 TWh by 2050[11].

[10] In the "Expansion Challenge" scenario of the National Energy Plan 2050 [1], an energy efficiency potential of 321 TWh is estimated in Brazil, which corresponds to 17% of the total electricity consumption in the horizon considered (2050). Given that the building sector is currently responsible for around 50% of total electricity consumption in Brazil, it is estimated that the potential for energy efficiency in the building sector will be around 161 TWh by 2050. The bases for estimating the percentage of the energy efficiency potential in the slow digitalization scenario are described in Chapter 2 (section 2.7 – item 2.7.3).

[11] See footnote 1. The bases for estimating the percentage of energy efficiency potential in the moderate digitalization scenario are described in Chapter 2 (section 2.7 – item 2.7.3).

Scenario C – Fast digitalization: Digitalization in the building sector is implemented at a rapid pace in the country, being strongly induced by the State, with broad participation of private investments and accelerated adoption of digital technologies. It covers all types of buildings, due to the effective integration between the various institutional and regulatory mechanisms aimed at digitalization, energy efficiency and housing. Many commercially available digital solutions are adopted at all phases of the building life cycle as early as the first decade. The energy efficiency potential resulting from rapid digitalization reaches levels of 30 to 40% of the total 161 TWh[12] by 2050.

In addition to the prospective scenarios, four case studies of smart buildings in Brazil, including housing of social interest, were presented. We sought, through the case studies, to highlight the energy savings due to the implementation of digital solutions for buildings of different types and at different phases of the life cycle.

This document is structured in four chapters, including this introduction. Chapter 2 proposes a conceptual model for the construction of alternative scenarios and then presents the results of the structural analysis of the key variables and the main actors, stakeholders, and influencers of the scenarios. The following characterizes political-regulatory and non-regulatory constraints that will shape the evolution of the most likely scenarios of energy efficiency potential, resulting from digitalization in the building sector in Brazil. The scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil are described, including:

i. Philosophy[13];
ii. Trajectory in the period 2022-2030[14];
iii. Trajectory in the period 2031-2050.

At the end, the main barriers to digitalization in the building sector are identified and analyzed, classifying them into institutional; market and financial; technical; and behavioral and skilled labor qualification barriers.

Chapter 3 describes four digitalization case studies in buildings of different types and phases of the life cycle, covering:

i. Architectural features;
ii. Energy efficiency initiatives;
iii. Description of digital solutions;
iv. Energy saving data.

The cases portrayed were:

i. Minha Casa + Sustentável (Rio de Janeiro – RJ) – project phase;
ii. AQWA Corporate (Rio de Janeiro – RJ) – design and operation phases;
iii. São Paulo Corporate Towers (São Paulo – SP) – design and operation phases;
iv. Gávea Planetarium (Rio de Janeiro – RJ) – renovation and operation phases.

Finally, in Chapter 4, recommendations are proposed to eliminate the barriers discussed at the end of Chapter 2, seeking to contribute to the formulation of public policies and actions aimed at digitalization and energy efficiency in the building sector in Brazil and reducing risks in decision-making processes, both in the public and private spheres.

[12] See footnote 1. The bases for estimating the percentage of the energy efficiency potential in the rapid digitalization scenario are described in Chapter 2 (section 2.7 – item 2.7.3).

[13] Philosophy of a scenario summarizes the movement or fundamental direction of the considered system. It translates the idea-force of the scenario.

[14] Trajectory refers to the route or path of the system in the considered period. It describes the movement or dynamics of this system, from the initial scene to the final scene of the period. In this study, two trajectories are defined to describe each scenario, namely: 2022-2032 and 2033-2050.

2. Scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil: horizon 2050

By building prospective scenarios, it is possible to abstract from the current situation and establish alternative future images for the increase in energy efficiency in the Brazilian buildings sector, resulting from digitalization in the coming decades. They aim to support the formulation of public policies directed towards this objective and reduce risks in decision-making processes, both in the public and private spheres.

Prospective scenarios are configurations of images of the future, conditioned and based on coherent games of hypotheses about the probable behaviors of the determining variables of the scenarization object [3]. Another important concept refers to critical uncertainties, defined as those phenomena or situations with a high degree of uncertainty and impact for the guiding question of the process of constructing prospective scenarios [4].

Initially, a conceptual model is proposed for the construction of alternative scenarios and, subsequently, the results of the structural analysis of the key variables are presented; the main stakeholders and influencers of the scenarios; the actual description of the scenarios, as well as constraints and barriers digitalization in the building sector on the horizon considered.

2.1 Conceptual model for constructing scenarios

There are several approaches and methods for constructing prospective scenarios, all with the objective of obtaining configurations of alternative medium and long-term futures, which should be used as instruments in planning at the macro level (countries and regions), at the sectoral level (sectors of the economy) and at the organizational (public, private and third sector organizations).

In this study, a mixed methodological approach was employed for the construction of alternative prospective scenarios, which combines the Global Business Network methodology [4] with tools proposed by Godet [3]. This approach consists of seven steps described below:

- **i.** Definition of the guiding question for the construction of the scenarios and time horizon to be considered;
- **ii.** Definition and classification of key variables, through the use of the structural analysis technique;
- **iii.** Identification of the main stakeholders and influencers of the scenarios;
- **iv.** Characterization of the current situation (2021) and identification of future constraints in the considered horizon[15];
- **v.** Construction of prospective scenarios, using the morphological investigation method [5]. This step also includes the verification of the consistency and plausibility of the configurations and the selection of the most probable scenarios;
- **vi.** Description of the most probable prospective scenarios, including: philosophy, trajectory in the period 2022-2032 and trajectory in the period 2033-2050;
- **vii.** Analysis of the barriers to the implementation of digitalization in the building sector in the horizon of 2050 and the strategic implications of the adoption of digital solutions to increase energy efficiency in this sector.

[15] Constraints of digitalization in the Brazilian building sector in the considered horizon are those phenomena that will shape the evolution of the most probable scenarios of energy efficiency potential, resulting from digitalization in the building sector in Brazil. They refer to driving forces, weighty tendencies, critical uncertainties, invariants, and future-bearing facts associated with the main issue object of the construction of the scenarios.

Picture 2.1 shows the conceptual model that was adopted in the construction of the prospective scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil, considering the horizon of 2050.

2.2 Guiding question and time horizon of the scenarios

The definition of the guiding question and the time horizon of the scenarios was conducted in a meeting with representatives of GIZ, the MME and the MDR on November 10, 2021.

At the time, the guiding question was fully aligned with the objective of this prospective study, which is “to offer a basis for the formulation of public policies aimed at increasing the energy efficiency of the building sector, through digital transformation in the country”. The time horizon was established in line with the horizon of the National Energy Plan – PNE 2050 [1].

As a result, we arrived at the following guiding question and the time horizon to be considered in the scenario, as stated below:

“What is the potential for energy efficiency resulting from digitalization in the building sector in Brazil in the 2050 horizon?”

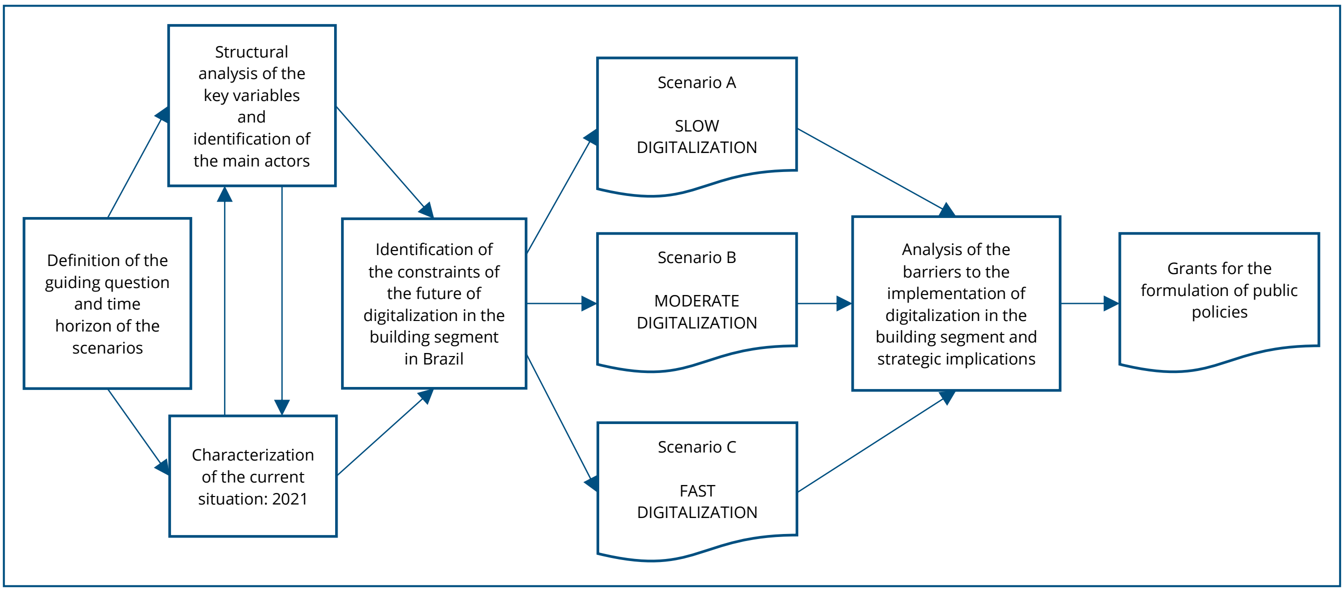
2.3 Structural analysis of key variables

In order to organize the vision of the technical team around a common basis for interpreting the issue to be scenarized, the structural analysis technique was used, which consists of the following steps:

i. Identification and description of key variables;
ii. Analysis of the relationships between the key variables, using the MICMAC[16] computational tool;
iii. Classification of key variables according to the influence and dependence between them;
iv. Drawing of the influence-dependence diagram resulting from the structural analysis.

Structural analysis allows describing a system through the construction of a matrix that relates all the constituent elements of that system. Based on this description, this tool aims to explain the main influential and dependent variables, considered essential to the evolution of the system. In this study, two meetings were held with the participation of all members of the technical team: the first for the identification and description of the key variables to be scenarized, and the second for the analysis of the relationships between the key variables, as described below.

As a result of the first meeting, a set of 14 key variables was arrived at, six external to the guiding question and eight internal, as presented in Table 2.1.



Picture 2.1 – Conceptual model for the construction of scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil. **Source: Made by the authors.**

[16] MICMAC (Cross-Impact Matrix – Multiplications Applied to a Classification). Computational tool available at: http://en.laprospective.fr/.

Table 2.1 – Key variables of the scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil – horizon 2050. **Source: Made by the authors.**

Key variable	Definition
Dynamics of the Brazilian Economy (ECON)	Evolution of the production of goods and services in the Brazilian economy, as well as the intensity of international relations and agreements and generation of jobs and income.
Public policies and energy efficiency programs in the country (POEE)	Public policies to promote the rational and efficient use of energy in different sectors of society, with a view to establishing a self-sustainable and autonomous energy efficiency market in Brazil.
Public policies and instruments for digitalization in the country (PODI)	Public policies and instruments aimed at the development, adoption and dissemination of digital solutions in the various sectors of the economy in the country.
Regulations for the modernization of the electricity sector in the country (RELE)	Regulations for the modernization of the electricity sector in the country, guided by the basic guideline of bringing electricity to consumers in a competitive manner, ensuring the sustainability of the expansion, with the promotion of market opening and efficiency in the allocation of costs and risks.
Public Housing Policy (POHA)	Policies aimed at the production of new housing units, aimed at addressing the country's housing deficit, including regularization of the land situation of subdivisions and complexes, and for the implementation of adequate infrastructure and urban equipment, including digitalization in the building sector.
Public and Private Investments for Digitalization (INDI)	Volume and distribution of public and private capital investments for digitalization in various sectors of the economy.
Technical standardization and regulations applicable to digitalization in the building sector (NODI)	Regulation of digitalization in the building sector and level of use of related technical standards applicable to the sector.
Multilevel training in digital solutions for professionals in the building sector (CAPE)	Multilevel training offer in digital solutions for professionals in the building sector.
User behavior regarding energy efficiency and sustainability of buildings (USEE)	Degree of acceptance (or resistance) of users regarding the implementation of the concept of energy efficiency and sustainability of buildings.
User behavior regarding building digitalization and cybersecurity (USDI)	Degree of acceptance (or resistance) of users regarding the use of digital and cybersecurity solutions in buildings.
Digitalization costs in the building sector (CUST)	Costs of acquiring, implementing and operating digital solutions in the building sector.
Brazilian Efficient Building Market (MREE)	Evolution of the efficient buildings market in Brazil in a given period.
Digitalization in the building sector in the country (DIGI)	Pace and speed of the implementation of digital solutions in the building sector in the country by phase of the life cycle.
Potential for increasing energy efficiency resulting from digitalization in the building sector in the country (EEDI)	Potential for increasing energy efficiency in the building sector resulting from the implementation of digital solutions in the considered horizon.

According to a systemic perspective, a variable only exists through the relationships it maintains with the other variables. Thus, structural analysis seeks to identify the relationships between the variables, using a double-input matrix called the structural analysis matrix. Qualitative completion of this matrix was performed by the technical team at the second structural analysis meeting, as follows: for each pair of variables, the following questions were asked – is there a direct influence relationship between variable *i* and variable *j*? If not, a rating of 0 is assigned; if on the contrary, it was asked whether this direct influence relationship was weak (1), medium (2) or strong (3).

Thus, with the support of the MICMAC computational tool, a matrix of direct influence of the key variables was arrived at (Picture 2.2). To verify the indirect influence of the key variables, successive multiplications of the direct influence matrix by itself were carried out until the ordering sequence of the variables remained stable.

The comparison of the hierarchy of variables in the different classifications (direct and indirect) revealed key variables that, due to their indirect influence on others, play a predominant role not perceived in the direct classification. Thus, by structural analysis, the classification of the 14 key variables was reached, according to their degree of influence and dependence. The influence-dependence diagram presented in Picture 2.3 refers to the indirect influence matrix.

As can be seen in Picture 2.3, the variables were grouped into five categories:

i. Determinant variables or driving forces;
ii. Surrounding variables;
iii. Connection variables;
iv. Regulatory variables;
v. Outcome variables.

	1 : ECON	2 : POEE	3 : PODI	4 : RELE	5 : POHA	6 : INDI	7 : NODI	8 : CAPE	9 : USEE	10 : USDI	11 : CUST	12 : MREE	13 : DIGI	14 : EEDI
1 : ECON	0	2	3	2	3	3	2	2	2	2	3	2	2	2
2 : POEE	1	0	1	2	1	1	0	1	3	1	1	3	2	3
3 : PODI	1	1	0	1	0	3	3	3	2	3	3	1	3	3
4 : RELE	1	2	1	0	0	1	1	1	3	1	3	2	1	1
5 : POHA	1	1	1	0	0	1	1	2	2	1	2	2	2	2
6 : INDI	2	1	3	1	1	0	3	3	1	3	3	1	3	3
7 : NODI	0	0	1	1	1	2	0	3	1	3	3	1	3	3
8 : CAPE	0	0	0	0	0	1	2	0	3	3	2	2	3	3
9 : USEE	0	1	1	1	0	0	1	1	0	2	2	3	2	2
10 : USDI	0	1	1	1	0	2	2	3	2	0	2	2	2	2
11 : CUST	1	1	2	1	1	3	3	3	1	3	0	1	2	2
12 : MREE	1	1	1	1	1	0	0	1	2	1	1	0	1	1
13 : DIGI	1	1	1	0	0	1	1	1	1	1	1	1	0	1
14 : EEDI	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: Degree of influence ranges from 0 to 3, where 0: no influence; 1: weak influence; 2: moderate influence; and 3: strong influence.

Picture 2.2 – Matrix of direct influence of the key variables of the scenarios. Source: Made by the authors.

Determinant variables or driving forces: They are located in the upper left quadrant of the influence-dependence diagram. They are the most relevant variables to explain the evolution of the issue object of the scenario together with the analysis of the conditions of the future associated with them, namely:

- Dynamics of the Brazilian Economy (ECON);
- Public policies and instruments for digitalization in the country (PODI);
- Public and private investments for digitalization in the most diverse sectors of the economy (INDI).

Surrounding variables: They are located in the upper left quadrant of the influence-dependence diagram, just below the set of determining variables. They refer to relevant environmental issues complementary to the determining variables:

- Public policies and energy efficiency programs in the country (POEE);
- Public housing policies (POHA);
- Regulations for the modernization of the electricity sector in the country (RELE).

Linking variables: they are located in the upper right quadrant and are highly influential and highly dependent variables. They refer to:

- Digitalization costs in the building sector (CUST);
- User behavior regarding the digitalization of buildings and cybersecurity (USDI);
- Technical standardization and regulations applicable to digitalization in the building sector (NODI);
- Multilevel training in digital solutions for professionals in the building sector (CAPI).

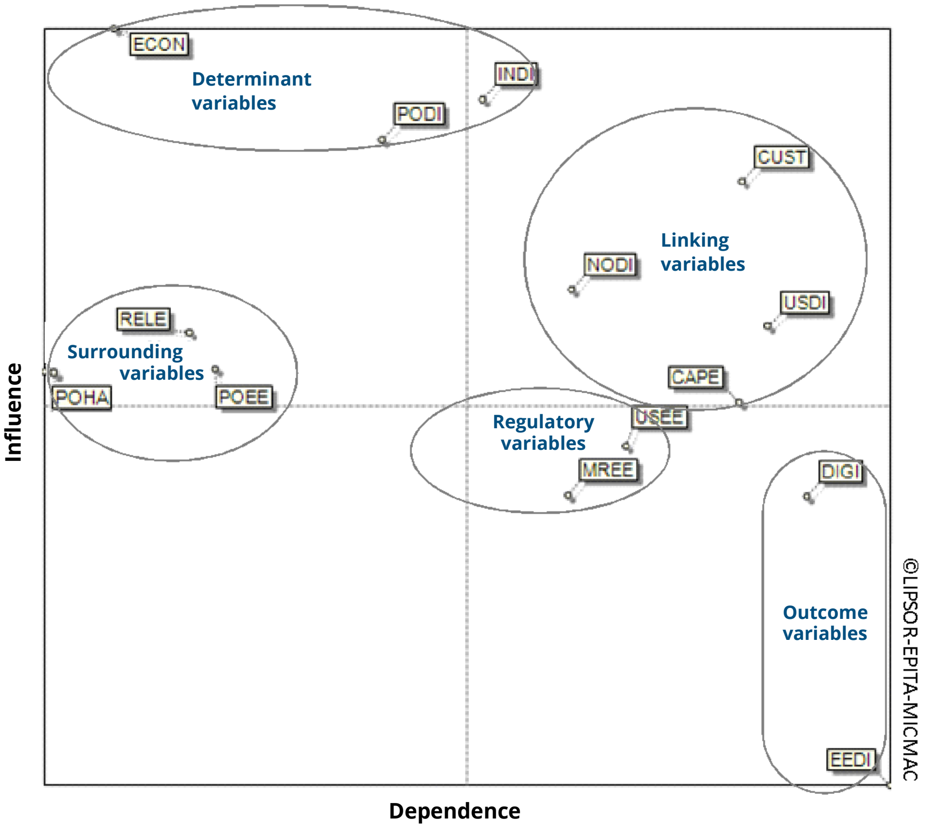
Regulatory variables[17]: Variables located in the central area of the influence-dependence diagram, which play a regulatory role in the evolution of the outcome variables. They are:

- User behavior regarding energy efficiency and sustainability of buildings (USEE);
- Brazilian Efficient Building Market (MREE).

Outcome variables: they are located in the lower right quadrant and are:

- Digitalization in the building sector in the country (DIGI);
- Potential for increasing energy efficiency resulting from digitalization in the building sector in the country (EEDI).

[17] The term "regulatory variables" is widely used in studies based on the theory of dynamic systems and refers to those variables that play a regulatory role in the evolution of the outcome variables of a given system. This term should not be confused with the term usually used to regulate productive activities.



Caption:

ECON – Dynamics of the Brazilian economy

PODI – Public policies and instruments for digitalization in the country

INDI – Public and private investments for digitalization

RELE – Regulation for the modernization of the electricity sector in the country

POEE – Public policies and energy efficiency programs in the country

POHA – Housing public policies

USDI – User behavior regarding the digitalization of buildings and cybersecurity

NODI – Technical standardization and regulation applicable to digitalization in the building sector

CUST – Digitalization costs in the building sector

CAPE – Multilevel training in digital solutions for professionals in the building sector

USEE – User behavior regarding energy efficiency and sustainability of buildings

MREE – Brazilian market for efficient buildings

DIGI – Digitalization in the building sector in the country

EEDI – Potential for increasing energy efficiency resulting from digitalization in the building sector in the country.

Picture 2.3 – Influence-dependence diagram of key variables. **Source: Made by the authors.**

2.4 Main stakeholders and influencers of the scenarios

For the construction of the scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil, in the horizon of 2050, two differentiated analyses of the social actors were carried out. In the first analysis, we sought to understand the power of the actors on the issue in focus, by their performance and influence on the key variables, particularly the determinant variables or driving forces and those of the surrounding area. In the second, the relations of the actors with each other were analyzed, with the objective of understanding the power structure as the basis for the recommendations presented in Chapter 4.

The results of the two analyses indicated that the Ministry of Mines and Energy (MME), the Ministry of Economy (ME) and the Ministry of Regional Development (MDR) constitute the most important actors due to their great capacity to influence the increase in energy efficiency in the building sector, resulting from digitalization in this sector (Picture 2.4).

Regulatory agencies (ANATEL and ANEEL), financial agents (BNDES, Caixa Econômica, public and private banks) and Municipal Public Administration bodies are at a second level. Companies in the production chain of the building sector also have a prominent position in the hierarchy, especially construction and developers, architectural, engineering and consulting services offices, as well as building managers and suppliers of materials and electronic equipment.

No less important in the hierarchy are the actors who act on key link variables, such as:

- **i.** Standardization and certification bodies acting on the variable “Technical standardization and regulation applicable to digitalization in the building sector” (NODI);
- **ii.** Universities, technical schools, research centers, startups and accelerators influencing the evolution of the variable “Multilevel training in digital solutions for professionals in the building sector” (CAPI);
- **iii.** Third sector organizations with an interest in energy efficiency and digitalization, influencing the behavior of building users;
- **iv.** Users, for the component of awareness of energy efficiency and the benefits of using digital solutions in their daily lives.

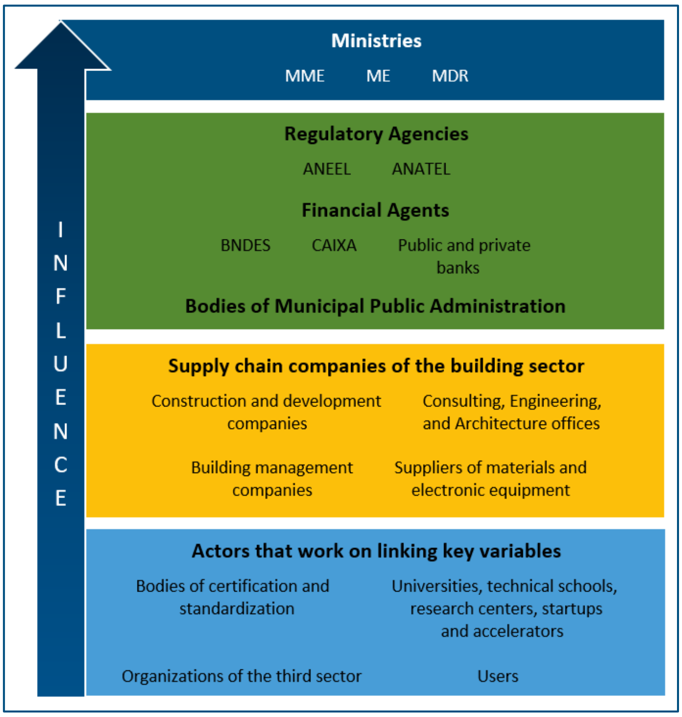
2.5 Current situation: Digitalization and energy efficiency in the building sector in Brazil in 2021

This section summarizes the indicators, events and changes in progress regarding the situation of digitalization and energy efficiency in the building sector in Brazil in 2021.

2.5.1 Dynamics of the Brazilian Economy (ECON)

Although the forecast of the Gross Domestic Product (GDP) for the year 2021 is 4.78% [6], in the last two years the economy has practically stagnated. In 2020, GDP retracted by 4.1% [7]. In addition, the Broad National Consumer Price Index (IPCA) is expected to reach 10.15% in 2021 [6], above the inflation target ceiling of 5.25% [8]. This predicted high inflation index is due to high global inflation, determined by the rapid recovery of the economy after the Covid-19 crisis, which meant that the productive sector was unable to meet the high demand for goods and services in the various countries of the global economy [8].

The rise in inflation in Brazil has been eroding household income. The average income of Brazilian families decreased by 11% in the third quarter of 2021, when compared to the same period in 2020 [9]. The vacancy rate, considering this same period, decreased by 2.2% [9].



Picture 2.4 – Map of the main stakeholders and influencers of the scenarios. **Source: Made by the authors.**

In relation to international agreements, especially with regard to the National Policy on Climate Change (PNMC) [10], Brazil committed itself in 2015 at the 2021 Conference of the Parties (COP21) to reduce greenhouse gas (GHG) emissions through its Nationally Determined Contribution (acronym in English, NDC) [11]. With regard to the energy sector, the country committed itself by 2030 to expand the domestic use of non-fossil energy sources, increasing the share of renewable energies (in addition to energy from water sources) and achieving 10% efficiency gains in this sector [11].

Recently, in December 2021, Brazil transmitted to the United Nations Framework Convention on Climate Change (UNFCCC) the new Nationally Determined Contribution to the Paris Agreement, approved at the time by the Interministerial Committee on Climate Change (CIM). The new Brazilian NDC reaffirms its commitment to reduce total net greenhouse gas emissions by 37% in 2025 and officially assumes the commitment to reduce Brazilian emissions by 43% by 2030 [12; 13].

In relation to Brazil's 2030 Agenda, with regard to the indicators related to the seventh Sustainable Development Goal (SDG 7) – Accessible and clean energy for all – improvements have been observed, especially due to the policies related to distributed generation in Brazil [14; 15]. However, in order to improve social inequality indicators, such as the Gini and Palma indexes, major challenges must be overcome so that the goals can be met, particularly the reduction of poverty and the favelization of Brazilian cities [14].

2.5.2 Public policies and energy efficiency programs in the country (POEE)

The current public policies and programs that can contribute to the promotion of the rational and efficient use of energy in different sectors of society, with a view to establishing a self-sustainable and autonomous energy efficiency market in Brazil, are [1]:

i. Brazilian Labeling Program;
ii. National Electric Energy Conservation Program (PROCEL);
iii. National Program for the Rationalization of the Use of Petroleum and Natural Gas Derivatives (CONPET);
iv. Ten-Year Energy Efficiency Plan (PDeF);
v. Energy Efficiency Program (PEE/ANEEL);
vi. Energy Efficiency Act (10,295/2001).

Regarding equipment labeling, the Brazilian Labeling Program (PBE), under the responsibility of Inmetro, PROCEL and CONPET, currently consists of 27 Conformity Assessment Programs at different phases of implementation, ranging from the labeling of white goods, such as stoves, refrigerators and air conditioners, to vehicles and buildings [16].

The three mechanisms to stimulate the use of energy-efficient products (i.e., minimum energy efficiency indices, National Energy Conservation Label – NECL and PROCEL Seal), which are intrinsically articulated, can be considered instruments of energy efficiency policy with greater effectiveness in Brazil, being responsible for a large part of the results of PROCEL's actions in 2020 [17].

Despite the results achieved so far, the certification of buildings in Brazil is voluntary and is compulsory only for buildings in the federal public sector.

2.5.3 Public policies and instruments for digitalization in the country (PODI)

Although some public policies and instruments aimed at the development, adoption, and dissemination of digital solutions in the various sectors of the economy have been adopted in Brazil, the effectiveness of these instruments is still very low.

One of the first digitalization actions focused on residential consumers in Brazil took place in 2003 with the installation of electronic meters by a distributor in Brazil. However, it was only in 2005 that ANEEL created a resolution on electronic measurement [18]. This resolution allowed the creation of two regulatory instruments to enable a demand response mechanism – the White Tariff.

Decree No. 9,612/2018 [19], which provides for public telecommunications policies (PPT), aims to promote the expansion of internet access and digital inclusion. This Decree defines one of the bases of the 5G auction. This auction took place in November 2021. Decree No. 9,854/2019 [20] established the National Internet of Things (IoT) Plan, whose purpose is to implement and disseminate the use of IoT in Brazil.

In 2019, the Chamber of Cities 4.0 was launched, which is a forum coordinated by the Ministry of Regional Development (MDR) and the Ministry of Technology and Innovations (MCTI), with the participation of public and private business, government and academic institutions [21]. In addition, a relevant initiative was the publication in 2020 of the “Brazilian Charter for Smart Cities” [19]. Finally, it is worth mentioning that Bill 976/2021, which establishes the National Smart Cities Policy (PNCI), is in progress in the Chamber of Deputies, aiming to stimulate the development of smart cities in the country [22].

2.5.4 Regulations for the modernization of the electricity sector in the country (RELE)

Since the discussions on the regulation for the modernization of the electricity sector in the country were opened, through Public Consultation No. 33/2017 [23], it can be said that its implementation stage is still low, despite the movements of the various agents of the electricity sector within the scope of the Working Groups established by the Electricity Sector Modernization Implementation Committee (CIM) [24]. This new milestone in the Brazilian electricity sector intends to bring electricity to consumers in a more competitive way, through the staggered opening of the market, ensuring the sustainability of the expansion and respect for legacy contracts. In this way, it seeks to ensure greater efficiency and safety of the system, in addition to optimizing the allocation of costs and mitigating risks.

In relation to some aspects of modernization that may impact the building sector, the incentive to expand demand management stands out, which is at a slow pace, despite the White Tariff legislation. The regulation of distributed generation, thanks to the incentives defined in Law 14,300/2022 [25], its effectiveness can be considered moderate.

2.5.5 Public Housing Policy (POHA)

In the sphere of housing public policies in force in the country, the Green and Yellow House Program (PCVA) stands out, created to replace the Minha Casa Minha Vida Program (PMCMV), with the objective of promoting the right to housing for families living in urban and rural areas, facilitating economic development and generation of work, raising housing standards and quality of life for Brazilians [26]. The Casa Verde e Amarela Program operates with several modalities – land regularization, improvement and financed housing production. Its main objective is to allow the low-income population to have access to their own home, improving the quality of life of Brazilians, which encompasses all housing service lines carried out from August 2020, in continuity with the My House My Life Program.

Under the PCVA, Ordinance No. 959/2021 [27] was recently launched, which provides for the requirements for the implementation of housing developments within the scope of the service line “Subsidized acquisition of new properties in urban areas, part of the Casa Verde e Amarela Program. Among the requirements for the execution of the work, the development of the project of the according to the methodology Building Information Modeling (BIM) stands out, complying with current Brazilian technical standards on the subject, and the use of a tool to calculate carbon emissions to assess greenhouse gas (GHG) emissions. Regarding the project design requirements, the certification of the Brazilian Labeling Program – PBE Edifica, BREEAM, LEED, AQUA or Casa Azul Seal + CAIXA stands out. As was the case with the PMCMV, institutions that wish to undertake the program must comply with the requirement to adhere to the Brazilian Habitat Quality and Productivity Program (PBQP-H). The Ordinance also emphasizes that in the absence of a Quality Sector Program (PSQ) /PBQP-H for a product or component, those that have certification issued by Product Certification Bodies (OCP) accredited by Inmetro must be used [27].

Also noteworthy is the role of the National Social Interest Housing System – SNHIS, established by Law No. 11,124/2005 [28], which aims to implement policies and programs that promote access to decent housing for the low-income population, which makes up almost the entire housing deficit in the country. In addition, this Law established the National Social Interest Housing Fund – FNHIS, which centralizes the budget resources of the Urbanization Programs for Precarious Settlements and Social Interest Housing, included in the SNHIS.

Due to the country's economic situation in the last three years, there was an increase in the housing deficit, which reached 5,877 million homes in 2019 [29]. The high value of urban rent accounts for more than half of the housing deficit in the country, about 3,036 million homes. This index fell between 2017 and 2018 but rose again in 2019.

2.5.6 Public and Private Investments for Digitalization (INDI)

Currently, the volume of investments for digitalization in various sectors of the economy comes predominantly from the public sector. The federal government, through the Ministry of Economy, has been investing in digital transformation in the public sector, with the objective of offering quality, more agile and less bureaucratic services. To date, more than 1,500 public services have been digitized [30].

With the 5G auction, the federal government raised R$ 47.2 billion, confirming the expectations of the government and the market [31]. However, this volume of investment in infrastructure, essential for the digitalization of the country, will only begin to be applied from 2022.

2.5.7 Technical standardization and regulations applicable to digitalization in the building sector (NODI)

The current level of technical standardization and regulation of digitalization in the building sector in Brazil is in an embryonic stage. Directly related to the sector, one can mention the ABNT Standard NBR 15965-1:2011 referring to the construction information classification system [32]. Although this Standard has been in existence for 10 years, its adoption is still low in the building sector in the country. Another important standard is the ABNT NBR ISO/IEC 27701:2019 [33] Standard, which refers to security techniques for managing information privacy – requirements and guidelines. This Standard is in line with the General Personal Data Protection Act (LGPD), Law No. 13,709/2018 [34].

2.5.8 User behavior regarding energy efficiency and sustainability of buildings (USEE)

The behavior of users regarding the energy efficiency and sustainability of buildings may vary according to the type of building. In residential buildings, according to data from the latest Possessions and Habits Survey (PPH) 2019, the vast majority of respondents stated that they always, or normally, adopt energy saving measures in their homes [35]. This research was limited to understanding the behavior of users in their homes. However, one fact draws attention, because although 81% of users said they would like to receive some type of information on how to conserve energy, only 41% said they received such information [35]. This shows that there is a willingness of users to inform themselves about energy efficiency, but they are unaware of the means to receive such information. It can be speculated that these users, if informed, would behave favorably to increase energy efficiency in their homes.

2.5.9 User behavior regarding building digitalization and cybersecurity (USDI)

The adoption of digital technologies in buildings in Brazil is still incipient and, consequently, the behavior of users regarding digitalization can be considered indifferent or even with some resistance to the use of these technologies, due to cybersecurity issues. Despite this, smart electricity meters, in their minimal version, can provide consumption data for the last hours, days, weeks, months or year. Although used by some distributors in Brazil as a non-technical loss reduction strategy, there are no easily accessible interfaces on these meters, which use BMS systems (Building Management/Control System) and virtual assistants. Although some devices with sensors have arrived on the market, which enable communication with energy consuming units, the adoption of such equipment is still very low in the country.

Especially in relation to cybersecurity, more and more users are concerned about the security of their data. In this context, the General Personal Data Protection Law (LGPD) was enacted to protect the fundamental rights of freedom and privacy and the free formation of the personality of each individual [34]. The Law talks about the processing of personal data, arranged in physical or digital media, carried out by an individual or legal entity governed by public or private law, encompassing a wide range of operations that may occur in manual or digital means.

2.5.10 Digitalization costs in the building sector (CUST)

Digitalization costs in the building sector are very difficult to estimate. In addition, the degree of adoption of digital technologies in this sector is still very low in the country, with few examples of digitalization in the building sector. Thus, for the dissemination of the use of digital technologies in this sector, large volumes of investment are required to be made by agents of the public or private sector. Such investments would, in theory, be offset and outweighed by efficiency gains and, more generally, by the added value that digitalization brings. However, the benefits provided by digital technologies are often not evident to those who are going to invest [36], being, therefore, a bottleneck for the entry of most digital technologies with application in the building sector in the national market [37].

2.5.11 Brazilian Efficient Building Market (MREE)

The mandatory labeling of energy efficiency in buildings in Brazil is exclusive to the federal public sector, according to Normative Instruction No. 2/2014, of the Ministry of Planning, Budget and Management [38]. The other types of buildings (single-family and multifamily residential, public, commercial and service) are not required to label energy efficiency. If the entrepreneur opts for labeling, the design and built building phases must be labeled, which apply to new buildings or renovations. There is still no label for the operation phase of the building.

Due to the fact that the labeling of energy efficiency in buildings is not mandatory in the country, the growth of this market is still very low. In 2018, only 224 commercial, service, and public buildings were labeled (93 related to built buildings) and only 5,356 residential labels issued for autonomous housing units [39]. However, it should be noted that some financial institutions already have interest-reduced credit lines for certified financing (Caixa Econômica Federal, for example).

2.5.12 Digitalization in the building sector in the country and energy efficiency (DIGI) (EEDI)

At the international level, the construction industry is among the least digitized productive sectors and the national reality follows the same picture [40]. It should be noted that the revolution is on its way, given the moment of technological transition, in which technologies are available but are not yet widely used, positioning Building Information Modeling (BIM) modeling as a potential communication hub between technologies and digital solutions [41], in tune with the National Strategy for the Dissemination of Building Information Modeling (BIM), instituted in 2018 by the Federal Government.

Today, the degree of digitalization in the building sector in Brazil is still low, especially due to the high investment costs and the difficulty of estimating the benefits provided by digital technologies in this sector. Digital solutions in buildings have been applied fundamentally in commercial buildings and corporate profile services.

By way of illustration, Chapter 3 presents four case studies, seeking to highlight the potential of increasing energy efficiency from digitalization in buildings of different types and at different phases of the life cycle of buildings.

2.6 Constraints of the future

The identification and classification of the key variables by structural analysis allowed the analysis and selection of the conditioning factors of the future, that is, those relevant phenomena that will shape the evolution of the most probable scenarios of the energy efficiency potential of buildings in Brazil, resulting from digitalization in the sector in focus.

Based on the analysis of the current situation (2021), the experience of the team and the results of the semi-structured interviews conducted with specialists during the month of November 2021, 22 constraints for the future were identified, eleven political-regulatory and eleven non-regulatory. The conditions selected at this phase are presented below, with the synthetic characterization of the identified process.

2.6.1 Political-regulatory constraints

Integration of public policies and energy efficiency mechanisms and continuity of the National Electric Energy Conservation Program – PROCEL

It is considered of fundamental importance for the scenarios of the potential to increase energy efficiency in the building sector, resulting from digitalization in the period from 2022 to 2050, the integration of existing public policies and energy efficiency mechanisms[18] and the continuity of the National Program of Electric Energy Conservation (PROCEL).

PROCEL is a government program, coordinated by the Ministry of Mines and Energy (MME) and executed by Eletrobras, to promote the efficient use of electricity and combat its waste. PROCEL's actions contribute to increasing the efficiency of goods and services, to the development of habits and knowledge about efficient energy consumption and, in addition, postpone investments in the electricity sector, thus mitigating environmental impacts and contributing to a more sustainable Brazil. PROCEL focuses of action include the National Building Energy Efficiency Program (PROCEL Edifica), established in 2003 by Eletrobras/PROCEL.

The Program promotes the rational use of electricity in buildings since its foundation, and with the creation of PROCEL Edifica, the actions were expanded and organized with the objective of encouraging the conservation and efficient use of natural resources (water, light, ventilation, etc.) in buildings, reducing waste and the impacts on the environment. The consumption of electrical energy in buildings correspond to approximately 45% of the consumption billed in the country. A potential reduction of this consumption is estimated by 50% for new buildings and 30% for those that promote reforms that contemplate the concepts of energy efficiency in buildings. Seeking the development and dissemination of these concepts, PROCEL Edifica operates around the following aspects: training; technology; dissemination; regulation; housing and efficiency and planning [42].

Continuity of the Brazilian Building Labeling Program – PBE Edifica

Another important political-regulatory condition of the scenarios of the potential to increase energy efficiency in the building sector in Brazil is the continuity of the Brazilian Building Labeling Program – PBE Edifica. Within its scope, the Technical Quality Requirements for the Energy Efficiency Level of Commercial, Service and Public Buildings (RTQ-C) and the Technical Quality Regulation for the Energy Efficiency Level of Residential Buildings (RTQ-R) and their complementary documents were defined, such as Conformity Assessment Requirements for Building Energy Efficiency (RAC) and the Manuals for the application of RTQ-C and RTQ-R. The RTQ-C and RTQ-R contain the necessary requirements for classifying the energy efficiency level of buildings. The RAC presents the procedures for submission for evaluation, rights and duties of those involved, the NECL model, the list of documents that must be submitted, model forms for completion, among others. It is the document that allows the building to obtain the National Energy Conservation Label (NECL) from Inmetro [43].

Recently, the Ministry of Economy/Inmetro approved on March 09, 2021 the new Inmetro Normative Instruction for the Energy Efficiency Classification of Commercial, Service and Public Buildings (INI-C), which improves the Technical Quality Requirements for the Energy Efficiency Level of Buildings Commercial, Utility and Public (RTQ-C), specifying the criteria and methods for the classification of commercial, service and public buildings for their energy efficiency [44].

According to the already approved Final Ordinance of INI-C, the issuance of labels based on the new method is subject to the publication of the Conformity Assessment Requirements (RAC) for Energy Efficiency of Buildings, which contains the procedure for this purpose. The proposed text of the Definitive Ordinance regarding the Conformity Assessment Requirements for the Energy Efficiency of Buildings, which apply to commercial, service, public and residential buildings – new or existing – entered into public consultation in March 2021, to present suggestions and criticisms regarding the proposed text [44]. The Inmetro Normative Instruction for residential buildings, and the respective RAC annex referring to this typology, are under development.

[18] Brazilian Labeling Program; National Electric Energy Conservation Program (PROCEL); National Program for Rationalizing the Use of Petroleum and Natural Gas Derivatives (CONPET); National Energy Efficiency Plan (PNEf); Energy Efficiency Program (PEE/ANEEL); Energy Efficiency Law (10,295/2001); Normative Instruction SLTI No. 02/2014/MPOG.

Implementation of the National Climate Change Policy – PNMC and the Nationally Determined Contribution (NDC)

The National Policy on Climate Change (PNMC) was instituted in 2009 by Law No. 12,187, seeking to ensure that economic and social development contributes to the protection of the global climate system [10]. According to Decree No. 7,390/2010, which regulates the PNMC, the greenhouse gas emissions baseline for 2020 was estimated at 3,236 $GtCO_2$-eq.

The Senate approved Bill No. 6539/2019, modifying Law 12,187/2009 that established the National Policy on Climate Change (PNMC), to include the commitments assumed by Brazil in the Paris Agreement, an instrument signed in 2015 [12]. The Agreement established targets for reducing greenhouse gas emissions, the Nationally Determined Contribution (NDC), with the objective of keeping the increase in global average temperature below 2 °C in relation to pre-industrial levels.

In December 2021, Brazil transmitted to the United Nations Framework Convention on Climate Change (UNFCCC) the new NDC to the Paris Agreement, approved at the time by the Interministerial Committee on Climate Change (CIM). Based on 2005, the Brazilian NDC reaffirms its commitment to reduce total net greenhouse gas emissions by 37% in 2025, and officially assumes the commitment to reduce Brazilian emissions by 43% by 2030 [13]. The NDC also sets out the country's indicative objective of achieving climate neutrality – that is, zero net emissions – by 2060. This long-term objective could be revised in the future, depending on the functioning of the market mechanisms of the Paris Agreement.

Facilitating instruments for access to credit for energy efficiency

Among the instruments that facilitate access to credit for energy efficiency that can be used by agents in the building sector in Brazil, the Guarantee Fund for Energy Efficiency Credit (FGenergia), created by the National Bank of Economic and Social Development (BNDES) with a contribution initial amount of R$ 30 million from the National Electric Energy Conservation Program (PROCEL). The expectation is that FGenergia enables the generation of guarantees for around R$ 200 million in energy efficiency projects throughout Brazil [45].

These non-reimbursable resources will be used to support energy efficiency projects through the granting of guarantees. Energy efficiency projects from different sectors of the economy, including the building sector, may be contemplated. The Fund's guarantee mechanism provides for the coverage of part of the risk of financial agents with these operations, by granting a guarantee that may reach 80% of the total credit and will be subject to the validation of technical criteria of the project related to energy efficiency.

Proposed changes to the regulatory framework of the electricity sector

Ordinance MME No. 187, of April 04, 2019, established Working Group – WG to improve proposals that enable the Modernization of the Electricity Sector based on the pillars of governance, transparency and legal-regulatory stability. The Group was formed by the following units of the MME: Executive Secretariat (coordinator of the work), Department of Electric Energy, Secretariat of Energy Planning and Development, Special Advisory on Economic Affairs and Legal Counsel. The National Electric Energy Agency – ANEEL, the Electric Energy Trading Chamber – CCEE, the Energy Research Company – EPE and the National System Operator – ONS also participated in the working group meetings, which took place weekly, as well as representatives of civil society, associations and specialists from other bodies and entities, who were invited to participate in the meetings. After the completion of the work, the Group presented to the Minister of Mines and Energy an Action Plan and proposals for regulatory acts relevant to modernization, pointing to the need to implement short, medium- and long-term measures (88 actions divided into 15 fronts of action). Among the proposals, the MME Ordinance No. 403, signed on October 29, 2019, which established the Modernization Implementation Committee – CIM [46] stands out.

National Smart Cities Policy (PNCI)

The Urban Development Committee of the Chamber of Deputies approved the proposal of Bill No. 976/21, which establishes a policy to stimulate the development in Brazil of so-called smart cities, which take advantage of state-of-the-art technologies in the management of urban space and in the relationship with citizens. The text is pending before the Chamber of Deputies. The proposal conceptualizes smart city as an "urban space oriented towards investment in human and social capital, sustainable economic development, and use of technologies available to improve and interconnect the services and infrastructure of cities, in an inclusive, participatory, transparent and innovative way, focusing on raising the quality of life and well-being of citizens" [21].

Among the principles that should govern smart cities are innovation in the provision of public services, respect for privacy, environmental sustainability, and the knowledge-based economy. The ultimate goal, according to the authors of the project, is to make public services more efficient and improve the quality of life of citizens. Based on the National

Smart Cities Policy (PNCI), municipalities must adopt smart city plans, duly approved by municipal law and integrated with the local master plan, when any, or Integrated Urban Development Plan, in the case of metropolitan regions. Citizens should participate in the preparation of the plans, indicating the digital transformations they wish to see implemented in their cities.

In order to facilitate the work of municipalities, the Federal Government will provide a repository of solutions aimed at the development of smart cities. Cities that adopt these solutions will have priority in accessing technical and financial assistance provided by the federal government. Priority will also be given to municipalities that have periodic training programs for public managers. Financial resources will come from the National Smart City Development Fund (FNDCI). The fund will be managed by a Board of Directors, which will have a managerial and regulatory character, and will include representatives of the federal government, state and municipal governments, workers, entrepreneurs, and the scientific and technological community, among others [21].

Revision of the National Housing Plan with expected validity until 2040 (PlanHab 2040)

The Federal Government, through the Ministry of Regional Development (MDR), initiated in the course of 2021 a series of dialogues for the construction of the National Housing Plan, with expected validity until 2040 (PlanHAB 2040) [47]. The instrument will serve as the basis for the planning and implementation of the Federal Government's housing policy over the next two decades. The process of preparing the Plan HAB 2040 is expected to be completed in 2022. Until then, technical studies and proposals for the implementation and monitoring of measures and mechanisms to address the housing issue in the different regions of the country will be formulated and debated, with the contribution of agents from the production chain, civil society and local governments. PlanHAB 2040 is thus configured as a dynamic tool for planning public housing policy in Brazil, based on a technical process that allows mapping the main bottlenecks of the housing sector in the country, as well as designing future planning scenarios. On the other hand, it adopts a perspective of support and consultation with the extensive network of actors involved with the theme in the country [47].

One of the challenges in the preparation of the Plan HAB 2040 will be the transversal approach to sustainability. In line with the Sustainable Development Goals and Goals (SDGs) and the New Urban Agenda, PlanHAB 2040 should promote proposals and actions for a habitat with socio-environmental balance.

National Innovation Strategy

The National Innovation Strategy, published in July 2021, aims to bring a new paradigm to government management, seeking to increase the cohesion, synergy and effectiveness of policies aimed at innovation. The Strategy, composed of objectives, goals, and initiatives, organizes government priorities and forms the basis for the preparation of action plans. Complementing the process, the technical groups linked to the Innovation Chamber built five thematic action plans, one for each axis of the innovation policy. They are:

- **i.** Encouragement;
- **ii.** Technological base;
- **iii.** Education;
- **iv.** Market for innovative products and services;
- **v.** Culture of innovation.

The plans are composed of actions – new and ongoing – that offer concrete results by the end of 2022. It is worth mentioning the transversality of the plans, which received contributions from all the bodies of the Innovation Chamber, with about 80 employees participating directly in the group meetings, in addition to several others that offered relevant subsidies to the process [48].

General Personal Data Protection Law in Brazil

The General Personal Data Protection Law (LGPD) No. 13,709, of August 14, 2018 [34], provides for the processing of personal data, including in digital media, by a natural person or by a legal entity governed by public or private law, with the aim of protecting the fundamental rights of freedom and privacy and the free development of the personality of the natural person. Despite the fact that governance rules and good practices are mentioned in the Brazilian LGPD, the issues of data processing, systematic consumption measurements, privacy guarantees, and guidelines for the control and management of data use in the context of associated telecommunications and energy systems are still mentioned need to be established. They need to be characterized privacy conditions and use authorizations for data requiring systematic evaluation for decision-making, for example, to ensure local energy stability management when there are many connected prosumers [34].

Implementation of the National Strategy for the Dissemination of BIM in Brazil

Through the publication of Decree No. 9,377, of May 17, 2018, the federal government formalized the National Strategy for the Dissemination of Building Information Modeling (BIM), or BIM BR Strategy, with the purpose of promoting an environment suitable for investment in BIM and its dissemination in Brazil [49]. Among the established goals, it stands out that of increasing the implementation of BIM by 10 times, so that 50% of the GDP of civil construction has adopted the methodology by 2024. Currently, 9.2% of companies in the construction sector (which corresponds to 5% of the sector's GDP) use BIM in their work routines, according to research and studies by Fundação Getúlio Vargas (FGV) [49].

The proposal of the BIM BR Strategy is that the requirement of BIM in government purchases be made in a staggered manner, to allow time to adapt to the market and the public sector. Thus, the deadlines for implementation were: from January 2021, the BIM requirement will occur in the elaboration of models for architecture and engineering in the disciplines of structure, electrical, and hydraulic and Heating, Ventilation and Air Conditioning (HVAC) in the detection of interference, in the extraction of quantitative and in the generation of graphic documentation based on these models; starting in January 2024, the models should include some phases involving the work, such as planning the execution of the work, budgeting and updating of the models and their information as built. In addition to the requirements of the first phase; from January 2028, it will cover the entire life cycle of the work when considering post-work activities. It should be applied, at least, in new constructions, renovations, extensions or rehabilitations, when considered of medium or great relevance, in the uses foreseen in the first and second phases and, in addition, in the management and maintenance services of the project after its completion [49].

Use of BIM in the direct or indirect execution of engineering works and services conducted by federal public administration bodies and entities

Within the scope of the BIM BR Strategy, Decree No. 10,306, of April 02, 2020, established the use of BIM in the direct or indirect execution of works and services of engineering carried out by federal public administration bodies and agencies [50].

For the purposes of the provisions of this Decree, BIM or Building Information Modeling is defined as the set of technologies and integrated processes that allows the creation, use and updating of digital models of a building, in a collaborative way, that serves all participants in the project, in any phase of the construction life cycle. The implementation of BIM in the direct or indirect execution of engineering works and services performed by federal public administration bodies and entities should occur gradually, following the following phases [50].

First phase: from January 1, 2021, BIM should be used in the development of architectural and engineering projects, referring to new constructions, extensions or rehabilitations, when considered of great relevance for the dissemination of BIM, pursuant to the provisions of article 10, and shall cover, as a minimum:

- **i.** The elaboration of architectural models and engineering models referring to the disciplines of structures, hydraulic installations, heating, ventilation and air conditioning installations and electrical installations;
- **ii.** The detection of physical and functional interferences between the various disciplines and the revision of the architectural and engineering models, in order to make them compatible with each other;
- **iii.** The extraction of quantities;
- **iv.** The generation of graphic documentation, extracted from the aforementioned models.

Second phase: from January 1, 2024, BIM should be used in the direct or indirect execution of architectural and engineering projects and in the management of works, related to new constructions, renovations, extensions or rehabilitations, when considered of great relevance for the dissemination of BIM and will cover, at least:

- **i.** The uses envisaged in the first phase;
- **ii.** Budgeting, planning and control of the execution of works;
- **iii.** The updating of the model and its information as built (as built), for works whose architectural and engineering projects have been carried out or executed with the application of BIM.

Third phase: from January 1, 2028, BIM should be used in the development of architectural and engineering projects and in the management of works related to new constructions, renovations, extensions, and rehabilitations, when considered of medium or great relevance for the dissemination of BIM and will cover, in minimum:

- **i.** The uses envisaged in the first and second phases;
- **ii.** The management and maintenance of the project after its construction, whose architectural and engineering projects and whose works have been developed or executed with the application of BIM [50].

2.6.2 Non-regulatory constraints

Housing deficit mainly in large urban centers

The housing deficit throughout Brazil stands at 5.8 million homes, according to data reviewed by the João Pinheiro Foundation in partnership with the Ministry of Regional Development, base year 2019, concentrated in large urban centers [29]. The study also shows an increasing trend in the deficit. One of the causes for this growth is the excessive burden on urban rent, today characterized as the main component of the deficit. In the four years considered by the study, the number of vacant homes due to the high rent value jumped from 2.814 million in 2016 to 3.035 million in 2019. The number of homes that present some type of inadequacy reaches more than 24.8 million [29]. This indicator includes urban infrastructure characteristics, such as lack of water supply, sanitation, electricity, and solid waste collection. In addition to building inadequacies, such as lack of storage space, lack of bathroom, inadequate roof and floor, among others.

The National Housing Plan, expected to be effective until 2040 (PlanHAB 2040) will be the basic instrument for the planning and implementation of the Federal Government's housing policy over the next two decades. The effective implementation of PlanHAB 2040 will boost the evolution of the construction sector with regard to the supply of housing, especially for a social class with lower purchasing power. It will shape the entire housing sector, with the possibility of promoting a series of advances in standardization and standardization of materials and services, inclusion of digital technologies in the design and construction phases, among others [47].

It should be noted that the recent Ordinance No. 959/2021, of the Ministry of Regional Development, induces the inclusion of digital technologies in HIS, particularly the use of the BIM methodology [27]. The Brazilian Habitat Quality and Productivity Program (PBQP-H), of the Federal Government, also seeks to guarantee two fundamental points in HIS: quality, with works marked by safety and durability, and the productivity of the construction sector after its modernization [51].

Growing digitalization in various sectors of the country's economy, including the building sector

The Digital Government Strategy 2020-2022, established from Decree No. 10,332, of April 28, 2020 [52], establishes, among its goals, the digitalization of 100% of public services at the federal level and actions that simplify the life of citizens also in the states and municipalities, already with about 115 million registered users on the gov.br platform. Seventy-three federal agencies were involved and, so far, about 90% of the planned actions have been delivered [53], raising Brazil to the position of 7th country with high maturity in Digital Government in the world, according to a World Bank report published in 2021 [54].

With regard to the private sector, a recent study entitled "X-ray of digital transformation in Brazil in 2021" found that 45.7% of Brazilian companies are already implementing a digital transformation strategy, while 30.5% are currently developing a strategy and only 1.9% have no plans for digitalization [55]. The year 2020 was essential to boost the market, due to the impact of the Covid-19 pandemic, leading to changes in consumer behavior, as well as the democratization of digital technologies.

In particular, with regard to the use of digital solutions by micro, small and medium-sized companies, the Brazilian Micro and Small Business Support Service (Sebrae) points out that 70% of micro and small businesses included the internet as a sales enhancement tool, and 23% launched their own website as a sales channel during the Covid-19 pandemic [56]. In the past year, there has been a sharp acceleration in the entrepreneurship rate by necessity, with more than 14 million new businesses, according to the Global Entrepreneurship Monitor (GEM) 2020 report fundamentally based on digital platforms [56].

In the building sector, digitalization is still growing at a slow pace, although some maturity points are beginning to be observed. Like the BIM methodology, which gradually begins to be implemented on a larger scale, especially in the design and reform phases, driven by regulatory, economic and technological aspects. The natural evolution of applications, virtual assistants, and intelligence equipment can also significantly increase the advance of digitalization in the building sector, especially in the residential, commercial and small service typologies.

Technological development and offer of digital solutions in the country

Detailed research on the *status quo* of technological development and the provision of digital solutions in the country was conducted in the first phase of this study [2, 57, 58]. Based on this research, Picture 2.5 depicts the stage of technological development and the offer of the 20 digital solutions addressed and associated services, by phase of the life cycle of the buildings.

It is important to note that the offer, by itself, is not equivalent to the wide adoption of technologies, and it is essential to clarify that the digitalization process is not restricted to the technologies mentioned here, given that research, development, evolution, and innovation are continuous. However, the offer of technologies and services is unquestionably a condition for the digitalization of buildings, directing efforts to stimulate their adoption to other conditionings, such as the supply or lack of specialized labor, incentives or cost reduction (mainly of implementation), the creation of business models that favor democratization, the perception of value by consumers, among other factors necessary for their maturity. In other words, the indications of development and availability, even if they do not indicate concrete adoption, represent a trend vector and invite the analysis of specific barriers.

Digital solution	Design	Construction	Operation	Renovation	Demolition
Building Information Modeling (BIM)	Commercially available	Commercially available	Commercially available	Commercially available	Commercially available
Building Energy Modeling (BEM) Urban Energy Modeling (UBEM)	Commercially available	Unavailable	Commercially available	Commercially available	Unavailable
Computational fluid dynamics (CFD)	Commercially available	Unavailable	Unavailable	Commercially available	Unavailable
Simulation of natural and artificial lighting	Commercially available	Unavailable	Unavailable	Commercially available	Unavailable
Energy Portfolio Management Systems	Commercially available	Unavailable	Commercially available	Commercially available	Unavailable
Software for Life Cycle Assessment (LCA)	Commercially available	Commercially available	Commercially available	Commercially available	Commercially available
3D printing	Unavailable	Under development	Unavailable	Under development	Unavailable
Augmented Reality	Commercially available	Commercially available	Commercially available	Commercially available	Commercially available
Blockchain	Under development	Under development	Under development	Under development	Under development
Agile Management Software	Commercially available	Commercially available	Unavailable	Commercially available	Unavailable
Building Management System (BMS)	Unavailable	Under development	Commercially available	Unavailable	Unavailable
Smart Sensors, Actuators, and Switches	Unavailable	Unavailable	Commercially available	Unavailable	Unavailable
Addressable Digital Lighting Interface (DALI)	Unavailable	Unavailable	Commercially available	Unavailable	Unavailable
Smart Facades and other systems	Unavailable	Unavailable	Under development	Unavailable	Unavailable
Virtual assistants	Unavailable	Unavailable	Commercially available	Unavailable	Unavailable
Smart apps and controls	Unavailable	Unavailable	Commercially available	Unavailable	Unavailable
Smart sockets and chargers for electric vehicles	Unavailable	Unavailable	Commercially available	Unavailable	Unavailable
Smart electrical and electronic equipment connected to the grid	Unavailable	Unavailable	Commercially available	Unavailable	Unavailable
Demand response applications, awareness and gamification	Unavailable	Unavailable	Under development	Unavailable	Unavailable
Cloud Computing	Commercially available	Commercially available	Commercially available	Commercially available	Unavailable

Caption: Commercially available | Under development | Unavailable

Picture 2.5 – Technological development and offer of digital solutions in Brazil. Source: [2, 57, 58].

Growing market for information security and data protection technologies and services in the country

The global cybersecurity market will experience an average annual growth rate of 12.5% over the five-year period and will move US$ 403 billion by 2027. The figures, if confirmed, will represent revenue growth of 228% compared to the estimated US$ 176.5 billion for 2020 – last year's balance sheet is still being consolidated [59].

In Brazil, according to the report entitled “2022 Global Digital Trust Insights”, published by PwC, about 83% of business organizations should increase investment in cybersecurity in 2022, in order to reduce the frequent hacker attacks recorded during the Covid-19 pandemic [60]. The number of companies that expect an increase in cyber spending for the coming year is higher among Brazilian companies, when compared to other organizations in the world.

This trend had already been observed in previous years, but it was accentuated with the acceleration of companies' digital processes and the mandatory remote work, brought about by the Covid-19 pandemic, in addition to the perception of greater exposure to cyber risks.

Introduction of 5G technology and expansion of 4G mesh

The acronym 5G refers to the fifth generation of cellular communication. This technology has the characteristic of supporting an increasing volume of information that is exchanged daily between various devices around the world. The highlight of 5G is the ability to operate in the millimeter wave band (a very high frequency spectrum, which ranges from 24 to 100 GHz). This allows data transfer much faster than the current one and promises to optimize the browsing speed of mobile devices, such as tablets and mobile phones. The expansion of the 5G network will directly impact the implementation of smart buildings and so-called “smart cities” with the offer of new products, services and possibilities. In practice, 5G could contribute widely to a more connected world and to the expansion of the Internet of Things, since the solution allows devices to establish a stable and fast connection with each other. The 5G auction that took place in November 2021 will introduce this network in the country.

In Brazil, due to its geographical characteristics and economic heterogeneity, it is also important to expand the current 4G network, with part of the investments already dampened to serve the part of society that does not have access to the internet or has precarious access.

Trend towards standardization of processes, materials and equipment in the building sector

Standardization understood as the establishment, communication, adherence to, and improvement of standards, which in turn requires unambiguous specifications on processes, materials, and equipment in the building sector. It is the basis for increasing the efficiency and effectiveness of production processes, reducing costs and waste throughout the construction chain. By way of illustration, the standardization of tests is essential for the consistency of energy performance data of materials that make up the basic layer of digital technology, such as BIM, that induce more energy efficient projects and constructions. Government housing programs, such as the Brazilian Habitat Quality and Productivity Program (PBQP-H), which seeks to increase the quality and durability of buildings of social interest and the productivity and modernization of the construction sector, emphasize that standardization instruments are its main foundations [51]. Examples of these instruments include the Services and Works Conformity Assessment System (SiAc); the Materials, Components and Construction Systems Companies Qualification System (SiMAC); and the National System of Technical Evaluations of Innovative Products and Conventional Systems (SiNAT).

Trend of human-centered building designs: user-centric design

Human-centered building projects (user-centric design) are based on a philosophy for the creation of products, services, hardware and software that meets the specific needs of customers and users. The trend is growing worldwide, as the likelihood of creating friendlier products or more comfortable architectural designs or accessibility products to meet a specific disability or health need increases [61].

Digital technologies align with this trend in various phases of the life cycle of a building, whether in the design phase with simulations guided by user behavior, or in operation with the use of technologies such as intelligent adapters, energy analyzers, decision support mechanisms occupant aware and mobile apps. Such technologies directly improve interactions between occupants and energy-consuming assets in their environment [61].

Technological Collaboration Programs under the International Energy Agency (IEA) have discussed and created conditions to understand the behavior of users and transform this knowledge into strategies to improve the performance of buildings. Among the study groups currently in operation, Annex 79 and Annex 87 of the Energy Technology Collaboration Program in Buildings and Communities (EBC-TCP) stand out. The first aims to provide a new vision of occupant behavior related to comfort in buildings and the impact on their energy performance. It seeks to further promote the use of this knowledge in construction design and operation processes, supporting policies, preparing proposals for standards, and providing guidance to stakeholders [62] [63]. The purpose of Annex 87, on the other hand, is to establish design criteria and operating guidelines for “customized environmental control systems” (PECS) and to quantify the benefits in relation to the health, comfort, and energy performance of buildings [64].

Insertion of the topic of digitalization in the curricula of vocational courses and higher education

Digitalization is a cross-cutting theme that permeates all training at both the vocational level and higher education. In buildings, the use of a large part of digital technologies is concentrated when considering the several types and phases of their life cycle. In the construction sector, dozens of different professions coexist that are witnessing the growth of the use of digital technologies and their rapid evolution. Professions considered non-technological based are challenged by the increasing use of these solutions in buildings, condominiums, and homes. In this way, it is urgent that professionals, both higher and middle level, become familiar with these technologies and be open to the emergence of new ones. The level of knowledge acts in a certain way as a regulatory factor for the adoption of these technologies. It is common to report building automation processes that did not maximize their gains due to the underutilization of the implemented digital solutions. The inclusion of the topic of digitalization in a more forceful way in the curricula of vocational courses and higher education will contribute to the dissemination of digital solutions in the most diverse sectors in general and in particular in the building sector.

A recent study, entitled “Professions of the future in the Energy Area and Implications for Vocational Training” [65], sought to systematize the research of the demand for professional training in the productive sector and the offer of qualification by educational institutions, carrying out a matchmaking analysis focusing on priority future occupations in the energy area.

The analyses focused on five main areas:

i. Renewable energy generation;
ii. Intelligent transmission and distribution grids;
iii. Electric mobility;
iv. Energy efficiency;
v. Demand response.

The latter area encompassed mechanisms that allow consumers to better manage energy use. The study pointed out that digitalization and computerization trends will require a greater presence of professionals with specialization in digital technologies, such as IoT, Digital Twin, Big Data and Machine Learning, as well as profiles in the areas of automation and cybersecurity, control and operation of systems. With the insertion of smart meters and other automated equipment, a gigantic mass of data emerges, with two profiles becoming fundamental: the data scientist, to collect, analyze and filter the data, and the data security professional, since smart meters, for example, trace a very detailed and specific consumer profile. Brazil's current offer still has little focus on handling large volumes of data, and only more recently have courses focusing on cybersecurity started to be offered [65].

Creation of new jobs related to digital demands of the building sector

Digital solutions naturally require specific maintenance, adjustments, configurations, customizations, but, above all, they require that the information collected by them be stored and interpreted, so that specific actions can be taken. Building Management Systems (BMS) management requires professionals with specific training and skills to perform this role. However, with the increase in the availability of programs and systems that can incorporate artificial intelligence (AI), based on the processing of Big Data and Machine Learning, new jobs related to digital demands of the building sector will require professionals with the indicated profiles in [65], as the data scientist, to collect, analyze, and filter the data, and the data security professional, by way of illustration.

These are the professionals able to structure and design specific data intelligence constructs adapted to the building, which assist the remote management of its systems by building resource management professionals, offering predictive and prescriptive analysis based on the information collected by the sensors present in the different building systems and making simpler decisions automatically.

With artificial intelligence support and specific information clippings and automatic analysis available, resource managers in buildings can operate remotely and serve multiple objects simultaneously, thus reducing operational costs for end users. This large volume of data may present vulnerabilities, so cybersecurity experts may be required to act as consultants. For more specific questions regarding the use of the building, citizen developers can build solutions autonomously. These are professionals who develop digital solutions for you, in your work area or company and who are not part of an IT department, although they are usually guided by technology specialists regarding the software to be adopted, and for training and support.

Greater user autonomy in the development and configuration of digital solutions

The introduction of low-code or no-code (LC/NC) platforms made it possible to develop integrated applications with advanced technologies. With the use of these platforms, more users are seeking to leverage their power and autonomy regarding the development and configuration of digital solutions [66]. Allied to the growing offer of low-code or no-code platforms, other factors such as the availability of free training by suppliers, democratization of the use of cloud computing, and dissemination of the concept of citizen development have given greater power and autonomy to the user in development and configuration of digital solutions in general and, in particular, for the building sector [67].

Increasing user confidence in data security

The digitalization of various sectors of the economy reflects directly on building users, notably the digital evolution of the electricity sector, which will require an intense exchange of data between consumers and the electrical system, with the management of an enormous volume of data. Regarding latest news of information leaks, mainly in Brazil, a recent study on security and data leakage indicated a 493% increase in leaks in 2019 compared to the amount of information that flowed through the networks in the previous year, leading to the growing concern of Brazilian society with digital security [68]. Another study, based on an online survey with the participation of 714 consumers from all over the country, aged 18 to 65, who should have carried out an online transaction in the last 12 months, showed consumers concerned about digital security [69]. The survey concluded that 67% of the people interviewed were very concerned about cybersecurity. This percentage varies with the age group, and the level of concern is lower among individuals aged 18 to 25 years (58%) and increases to the group of 46 to 55 years, which registers the highest level of concern (71%). This sentiment acts as a limiter to the adoption of digital technologies by both users, managers and entrepreneurs and can dictate the pace of adoption in some sectors, including in the building sector.

2.7 Scenarios of the energy efficiency potential resulting from digitalization in the building sector in Brazil in the 2050 horizon

Before beginning the actual description of the prospective scenarios, it is necessary to define which are the issues with a high degree of uncertainty and impact associated with the guiding question of the scenario construction process and describe the methodological bases for the construction of the scenarios and for the estimation of potential for energy efficiency resulting from digitalization in the building sector in Brazil, in the 2050 horizon in each scenario.

2.7.1 Critical uncertainties

Table 2.2 shows the critical uncertainties regarding the two key variables classified as outcome variables in the structural analysis (lower right quadrant of Picture 2.3). They are the digitalization in the building sector in the country and the potential for energy efficiency in the building sector resulting from the implementation of digitalization.

2.7.2 Methodological bases for the construction of prospective scenarios

As previously defined, prospective scenarios are configurations of images of the future conditioned and based on coherent games of hypotheses about the probable behaviors of the determining variables of the scenarization object [3].

To generate the prospective scenarios, a qualitative approach proposed by Godet [3] was chosen. The technical team employed the morphological investigation technique [5] in a structured participatory process aimed at constructing the generic morphological matrix with the hypotheses associated with the variables and respective parameters and identifying and selecting the coherent and technically logical combinations. It was also necessary to

Table 2.2 – Critical uncertainties to be scenarized. **Source: Made by the authors.**

Key variable	Critical uncertainties
Digitalization in the building sector in the country	• How will digitalization take place in the building sector in Brazil? • What digital solutions will enable fast, moderate, or slow digitalization scenarios, considering their implementation in the next decade? • What factors will influence the investment levels required for the digitalization of buildings in the three scenarios?
Potential for energy efficiency in the building sector, resulting from the implementation of digitalization	• What is the potential to increase energy efficiency in buildings, resulting from the implementation of digitalization by 2050?

analyze the consistency between the hypotheses defined for the critical uncertainties, seeking to select those combinations that, in addition to being consistent, were considered the most likely. The morphological matrices presented in item 2.7.4 present the most probable configurations for slow, moderate, and fast digitalization scenarios in the building sector in Brazil, considering the 2050 horizon. Therefore, three consistent and probable configurations were achieved, as shown in Pictures 2.6 to 2.8.

The description of the three prospective scenarios associated with these configurations included the philosophy, which summarizes the movement or the fundamental direction of the system considered; the trajectory of the system in the period from 2022 to 2032, starting from the initial scene (2022), reaching the final scene of the period (2032); and the trajectory of system in the period from 2033 to 2050.

2.7.3 Basis for estimating the energy efficiency potential resulting from digitalization in the building sector in Brazil in the 2050 horizon

Although the prospecting approach adopted in this study is qualitative in nature, we sought to estimate in percentage terms the potential for energy efficiency resulting from digitalization in the building sector in Brazil in the horizon 2050 in each scenario. To this end, assumptions were defined based on the configurations represented in Pictures 2.6 to 2.8, on the projections of electricity consumption and energy efficiency potential of the National Energy Plan – PNE 2050 [1] and on documentary research covering recent studies on digitalization and energy efficiency published by two international organizations – the International Energy Agency (IEA) and the United Nations (UN) [70-74].

According to these studies, digitalization can offer an enormous opportunity to maximize benefits in all energy-consuming sectors and face the challenges of lack of data or information, which lead to inefficient decision-making processes. They highlight three key sectors: buildings, industry, and transportation. Particularly in relation to buildings, the studies highlight the potential of digitalization in reducing the energy consumption of buildings by about 10% by 2040.

That said, the assumptions for the quantitative estimation of the energy efficiency potential resulting from digitalization in the building sector in Brazil were defined in Table 2.3, considering the horizon of 2050. It should be noted that the hypotheses defined for this variable were generated according to the two scenarios of the PNE 2050 [1], they were parameterized with the projections of the "Expansion Challenge" scenario, aiming to allow direct comparison between the percentage ranges of the energy efficiency potential, according to shown in Pictures 2.6 to 2.8.

2.7.4 Most likely configurations for digitalization scenarios in the building sector

Pictures 2.6 to 2.8 represent the most probable configurations for the digitalization scenarios in the building sector in the 2050 horizon, generated by the technical team in a structured participatory process, after the construction of the morphological space with the hypotheses defined for all variables and respective parameters.

Table 2.3 – Bases for estimating the energy efficiency potential resulting from digitalization in the building sector in Brazil: 2022-2050. Source: Made by the authors.

Parameter	Scenario A Slow digitalization	Scenario B Moderate digitalization	Scenario C Fast digitalization
Economic growth rate in the period 2022-2050	1.8% a year Scenario "Stagnation" of PNE 2050 [1]	2.8% a year "Expansion Challenge" scenario of the PNE 2050 [1]	
Potential electricity consumption in all sectors: horizon 2050	Around 893.50 TWh, based on the "Stagnation" scenario of the PNE 2050 [1]	Around 1888.23 TWh, based on the "Expansion Challenge" scenario of the PNE 2050 [1]	
Total electricity consumption in the building sector: horizon 2050	About **151.90 TWh**, based on the "Stagnation" scenario of the PNE 2050 [1]	Around **944.10 TWh**, based on the "Expansion Challenge" scenario of the PNE 2050 [1]	
Potential for energy efficiency in all sectors: horizon 2050	10%* of consumption of electrical energy, which corresponds to 89.35 TWh in the scenario "Stagnation" of the PNE 2050. (*) % of EE in the PNE 2030.	17% of electricity consumption, which corresponds 321 TWh in the "Expansion Challenge" scenario of the PNE 2050 [1]	
Potential for energy efficiency in the building sector: horizon 2050	Around **44.67 TWh**, based on the "Stagnation" scenario of the PNE 2050 [1]	About 8,5% of electricity consumption, which corresponds to **161 TWh** in the "Expansion Challenge" scenario of the PNE 2050 [1]	
Mandatory energy efficiency labeling by phase of the life cycle and by type	Mandatory requirement restricted by phase: project and renovation. Mandatory for certain types. Note: Today, the obligation is for federal public buildings of the Direct, Municipal and Foundational Administration.	Mandatory requirement restricted by phase: project and renovation. Mandatory for all types. Note: Today, a regulatory impact analysis (AIR) for mandatory labeling is underway.	Mandatory requirement restricted by phase: Project, operation and renovation. Mandatory for all types. Note: Today, the development of consumption benchmarks for buildings of different types is underway.
Implementation of digital solutions by life cycle phase	Picture 2.9	Picture 2.10	Picture 2.11 for all types
International references on the potential for energy efficiency in the building sector resulting from digitalization in the world	**10%** of total energy consumption in the building sector [70-74]		
Lower and upper limits for estimation of EE potential in the building sector	**Lower limit:** 10%* of 151.90 TWh** = 15.19 TWh. * [70-74] ** Scenario "Stagnation" of the PNE 2050 [1]	**Upper limit:** 10%* of 944.10 TWh** = 94.41 TWh. * [70-74] ** Scenario "Expansion Challenge" of the PNE 2050 [1]	
Estimate of EE potential in the building sector, according to the lower and upper limits	Estimate compatible with lower limit: 15.19 TWh/161 TWh = 9.4%	Estimate compatible with upper limit: 94.41 TWh/161 TWh = 58.3%	
Potential for energy efficiency in the building sector resulting from digitalization	Up to 10% of 161 TWh: up to 16.1 TWh	20-30% of 161 TWh: 32.2 – 48.3 TWh	30-40% of 161 TWh: 48.3 – 64.4 TWh
Avoided emission of CO_2 equivalent (tCO_2)	Up to 203,504 tCO_2 [75;76]	407,008 – 610,512 tCO_2 [75;76]	610,512 – 814,016 tCO_2 [75;76]

Scenario A – Slow digitalization						
Variable	**Parameters**	**Hypotheses**				
Dynamics of the Brazilian Economy (ECON)	Evolution of economic indicators	Accentuated decrease	Moderate decrease	**Stagnation**	Moderate growth	Accentuated growth
	Intensity of international relations and agreements (RAI)	Very low	**Low**	Moderate	High	Very high
Public policies and energy efficiency programs in the country (POEE)	Effectiveness of policies and programs	Low	**Moderate**	High		
Public policies and instruments for digitalization in the country (PODI)	Effectiveness of policies and instruments	**Low**	Moderate	High		
Public Housing Policy (POHA)	Effectiveness of public housing policies	Low	**Moderate**	High		
Regulations for the modernization of the electricity sector in the country (RELE)	Encouraging the expansion of demand management	**Slow expansion**	Moderate expansion	Fast expansion		
	Encouraging distributed generation	Limited coverage	**Medium coverage**	Broad coverage		
	Encouraging the commercialization of energy	Limited coverage	**Medium coverage**	Broad coverage		
Public and Private Investments for Digitalization (INDI)	Digitalization pace in various sectors of the economy	**Slow with a predominance of public investments**	Moderate with increasing participation of private investments	Fast with public and private investments		
Technical standardization and regulations applicable to digitalization in the building sector (NODI)	Maturity level of standardization processes technique and applicable regulations	Embryonic	**Development**	Growth	Mature	
	Degree of adoption of standards and regulations	Incipient adoption	**Low adoption**	Medium adoption	High adoption	
Multilevel training in digital solutions for professionals in the building sector (CAPE)	Degree of training	Very low	**Low**	Medium	High	Very high
User behavior regarding energy efficiency and sustainability of buildings (USEE)	Degree of user awareness	Very low	**Low**	Medium	High	Very high
	Culture regarding the use of sustainable solutions	Very unfavorable	Unfavorable	**Indifferent**	Favorable	Very favorable
User behavior regarding building digitalization and cybersecurity (USDI)	Degree of user awareness	Very low	**Low**	Medium	High	Very high
	Culture regarding the use of digital solutions	Very unfavorable	Unfavorable	**Indifferent**	Favorable	Very favorable
Digitalization costs in the buildings (CUST)	Availability of new digital solutions	Very low	Low	**Medium**	High	Very high
	Digitalization costs in the building sector	Very low	Low	Medium	**High**	Very high
Brazilian Efficient Building Market (MREE)	Growth of the efficient buildings market in the country	**Very low**	Low	Medium	High	Very high
	Mandatory energy efficiency labeling by phase of the building life cycle	No obligation	**Restricted obligation: project and renovation**	Restricted obligation: design, operation and renovation		
	Mandatory energy efficiency labeling by type	No obligation	**Mandatory for certain types**	Mandatory for all types		
Digitalization in the building sector in the country (DIGI)	Digitalization pace in the building sector	**Slow**	Moderate	Fast		
	Digital solutions implemented by phase of the building life cycle	**Morphological matrix of digital solutions implemented by life cycle phase: Picture 2.9**				
	Investments in digitalization in the building sector in the country	Low, due to the massification of digital technologies	Medium, depending on public or private induction	**High, due to low technological diffusion**		
Potential for increasing energy efficiency resulting from digitalization in the building sector in the country (EEDI)	Energy efficiency potential by 2050 Base: 161 TWh in the "Expansion Challenge" scenario of National Energy Plan 2050 [1]	**Up to 10% of 161 TWh**	10-20% of 161 TWh	20-30% of 161 TWh	30-40% of 161 TWh	Greater than 40% of 161 TWh

Picture 2.6 – Most likely configuration for scenario A – Slow digitalization. **Source: Made by the authors.**

Scenario B – Moderate digitalization							
Variable	**Parameters**	**Hypotheses**					
Dynamics of the Brazilian Economy (ECON)	Evolution of economic indicators	Accentuated decrease	Moderate decrease	Stagnation	**Moderate growth**	Accentuated growth
	Intensity of international relations and agreements (RAI)	Very low	Low	**Moderate**	High	Very high
Public policies and energy efficiency programs in the country (POEE)	Effectiveness of policies and programs	Low	**Moderate**	High		
Public policies and instruments for digitalization in the country (PODI)	Effectiveness of policies and instruments	Low	**Moderate**	High		
Public Housing Policy (POHA)	Effectiveness of public housing policies	Low	**Moderate**	High		
Regulations for the modernization of the electricity sector in the country (RELE)	Encouraging the expansion of demand management	Slow expansion	**Moderate expansion**	Fast expansion		
	Encouraging distributed generation	Limited coverage	Medium coverage	**Broad coverage**		
	Encouraging the commercialization of energy	Limited coverage	**Medium coverage**	Broad coverage		
Public and Private Investments for Digitalization (INDI)	Digitalization pace in various sectors of the economy	Slow with a predominance of public investments	**Moderate with increasing participation of private investments**	Fast with public and private investments		
Technical standardization and regulations applicable to digitalization in the building sector (NODI)	Maturity level of standardization processes technique and applicable regulations	Embryonic	Development	**Growth**	Mature	
	Degree of adoption of standards and regulations	Incipient adoption	**Low adoption**	Medium adoption	High adoption	
Multilevel training in digital solutions for professionals in the building sector (CAPE)	Degree of training	Very low	**Low**	Medium	High	Very high
User behavior regarding energy efficiency and sustainability of buildings (USEE)	Degree of user awareness	Very low	Low	**Medium**	High	Very high
	Culture regarding the use of sustainable solutions	Very unfavorable	Unfavorable	Indifferent	**Favorable**	Very favorable
User behavior regarding building digitalization and cybersecurity (USDI)	Degree of user awareness	Very low	Low	**Medium**	High	Very high
	Culture regarding the use of digital solutions	Very unfavorable	Unfavorable	**Indifferent**	Favorable	Very favorable
Digitalization costs in the buildings (CUST)	Availability of new digital solutions	Very low	Low	**Medium**	High	Very high
	Digitalization costs in the building sector	Very low	Low	**Medium**	High	Very high
Brazilian Efficient Building Market (MREE)	Growth of the efficient buildings market in the country	Very low	Low	**Medium**	High	Very high
	Mandatory energy efficiency labeling by phase of the building life cycle	No obligation	**Restricted obligation: project and renovation**	Restricted obligation: design, operation and renovation		
	Mandatory energy efficiency labeling by type	No obligation	Mandatory for certain types	**Mandatory for all types**		
Digitalization in the building sector in the country (DIGI)	Digitalization pace in the building sector	Slow	**Moderate**	Fast		
	Digital solutions implemented by phase of the building life cycle	**Morphological matrix of digital solutions implemented by life cycle phase: Picture 2.10**				
	Investments in digitalization in the building sector in the country	Low, due to the massification of digital technologies	**Medium, depending on public or private induction**	High, due to low technological diffusion		
Potential for increasing energy efficiency resulting from digitalization in the building sector in the country (EEDI)	Energy efficiency potential by 2050 Base: 161 TWh in the "Expansion Challenge" scenario of National Energy Plan 2050 [1]	Up to 10% of 161 TWh	10-20% of 161 TWh	**20-30% of 161 TWh**	30-40% of 161 TWh	Greater than 40% of 161 TWh

Picture 2.7 – Most likely configuration for scenario B – Moderate digitalization. **Source: Made by the authors.**

Scenario C – Fast digitalization						
Variable	**Parameters**	**Hypotheses**				
Dynamics of the Brazilian Economy (ECON)	Evolution of economic indicators	Accentuated decrease	Moderate decrease	Stagnation	**Moderate growth**	Accentuated growth
	Intensity of international relations and agreements (RAI)	Very low	Low	Moderate	**High**	Very high
Public policies and energy efficiency programs in the country (POEE)	Effectiveness of policies and programs	Low	Moderate	**High**		
Public policies and instruments for digitalization in the country (PODI)	Effectiveness of policies and instruments	Low	Moderate	**High**		
Public Housing Policy (POHA)	Effectiveness of public housing policies	Low	**Moderate**	High		
Regulations for the modernization of the electricity sector in the country (RELE)	Encouraging the expansion of demand management	Slow expansion	Moderate expansion	**Fast expansion**		
	Encouraging distributed generation	Limited coverage	Medium coverage	**Broad coverage**		
	Encouraging the commercialization of energy	Limited coverage	Medium coverage	**Broad coverage**		
Public and Private Investments for Digitalization (INDI)	Digitalization pace in various sectors of the economy	Slow with a predominance of public investments	Moderate with increasing participation of private investments	**Fast with public and private investments**		
Technical standardization and regulations applicable to digitalization in the building sector (NODI)	Maturity level of standardization processes technique and applicable regulations	Embryonic	Development	Growth	**Mature**	
	Degree of adoption of standards and regulations	Incipient adoption	Low adoption	Medium adoption	**High adoption**	
Multilevel training in digital solutions for professionals in the building sector (CAPE)	Degree of training	Very low	Low	Medium	**High**	Very high
User behavior regarding energy efficiency and sustainability of buildings (USEE)	Degree of user awareness	Very low	Low	Medium	**High**	Very high
	Culture regarding the use of sustainable solutions	Very unfavorable	Unfavorable	Indifferent	Favorable	**Very favorable**
User behavior regarding building digitalization and cybersecurity (USDI)	Degree of user awareness	Very low	Low	Medium	**High**	Very high
	Culture regarding the use of digital solutions	Very unfavorable	Unfavorable	Indifferent	**Favorable**	Very favorable
Digitalization costs in the buildings (CUST)	Availability of new digital solutions	Very low	Low	Medium	**High**	Very high
	Digitalization costs in the building sector	Very low	**Low**	Medium	High	Very high
Brazilian Efficient Building Market (MREE)	Growth of the efficient buildings market in the country	Very low	Low	Medium	**High**	Very high
	Mandatory energy efficiency labeling by phase of the building life cycle	No obligation	Restricted obligation: project and renovation	**Restricted obligation: design, operation and renovation**		
	Mandatory energy efficiency labeling by type	No obligation	Mandatory for certain types	**Mandatory for all types**		
Digitalization in the building sector in the country (DIGI)	Digitalization pace in the building sector	Slow	Moderate	**Fast**		
	Digital solutions implemented by phase of the building life cycle	**Morphological matrix of digital solutions implemented by life cycle phase: Picture 2.11**				
	Investments in digitalization in the building sector in the country	**Low, due to the massification of digital technologies**	Medium, depending on public or private induction	High, due to low technological diffusion		
Potential for increasing energy efficiency resulting from digitalization in the building sector in the country (EEDI)	Energy efficiency potential by 2050 Base: 161 TWh in the "Expansion Challenge" scenario of National Energy Plan 2050 [1]	Up to 10% of 161 TWh	10-20% of 161 TWh	20-30% of 161 TWh	**30-40% of 161 TWh**	Greater than 40% of 161 TWh

Picture 2.8 – Most likely configuration for scenario C – Fast digitalization. Source: Made by the authors.

2.7.5 Description of prospective scenarios

Scenario A – Slow digitalization

Philosophy

Digitalization in the building sector in Brazil occurs at a slow pace, with induction by the State limited to public buildings. Public housing policies emphasize housing of social interest (HIS). The use of digital solutions in HIS and the potential increase in energy efficiency are considered aspects of lesser relevance in view of the pressing need to reduce the housing deficit. The adoption of some digital solutions in the design, construction, operation and renovation phases of buildings occurs autonomously following the natural evolution of the market for these technologies in the country. As a result of the slow pace of digitalization in the sector, the potential for energy efficiency is low, at levels below 10% of the total 161 TWh[19] by 2050.

Trajectory 2022-2032

In the first decade of the slow digitalization scenario, there is a picture of economic stagnation with strong economic and financial bottlenecks, which prevent the advance of investments in digitalization in the most diverse sectors of the economy, including construction. There were low economic growth rates in the period, around 1.8% a year[20] [1]. Public policies and instruments to promote digitalization in the country are directed to some specific sectors. Particularly for the building sector, it is observed that the induction by the State is limited to a few initiatives in public buildings, which do not yet generate the expected results in the 2022-2032 trajectory.

In view of the representativeness of the building sector in the total consumption of energy and especially of electricity, opportunities for efficiency in the use of energy resulting from digitalization in the building sector appear in this first decade, but which cannot be fully exploited by the economic stagnation in the country. Energy efficiency labeling remains mandatory for public buildings of the direct, municipal and foundational public administration. The results of the regulatory impact analysis of the obligation for other types of buildings increase the benefits of labeling in this decade, due to the greater scope of the instrument. However, the growth of the efficient buildings market in the country is still considered low. It is considered that the institutional complexity and the challenges in the articulation of energy efficiency policies and mechanisms significantly hinder the integration of governance structures to optimize the allocation of existing resources, aiming to take advantage of these opportunities, which would lead to heating of the efficient buildings market.

The effectiveness of regulations for the modernization of the electricity sector in the country can be considered moderate in this trajectory, insofar as the incentives for distributed generation and the commercialization of energy have already been used with medium coverage in the country. However, the expansion of demand management occurs at a slow pace. With regard to public housing policies, given the pressing need to reduce the housing deficit, the use of digital solutions in housing of social interest (HIS) and the potential increase in energy efficiency are considered aspects of lesser relevance in this trajectory.

Digitalization in the building sector in this first decade is hampered by the relative slowness in the technical standardization and regulatory processes applicable to digitalization and by the level of qualification of specialized labor, considered low in this scenario. These limiting factors are combined with users' behavioral patterns reflected in a culture of indifference to the energy efficiency and sustainability of buildings, and also in relation to the benefits of digitalization in buildings. Not to mention users' concerns regarding potential cyber attacks.

Even with a slow pace of digitalization, some digital solutions [2; 57; 58] are used in the design, construction, operation and renovation phases of buildings already in the first decade, as shown in Picture 2.9. The offer of digital solutions in the country can be considered average, the costs of digitalization in the building sector are still high and the implementation takes place autonomously, following the natural evolution of the market for these technologies in the country.

Cloud computing evolves rapidly and acts as an enabler of virtually every digital solution available at varying degrees of maturity. Building Information Modeling reaches maturity in the project phase and consequently it is also used in the renovations. Although it is already beginning to be used in the other phases, especially in construction, it is not yet widely used. Although the technology is already available, there are still few cases suitable for use in the operation phase. With energy costs constantly rising and the gradual migration of the electricity sector to the provision of energy services and energy security, the escalation of distributed generation remains, so that energy

[19] In the "Expansion Challenge" scenario of the National Energy Plan 2050, an energy efficiency potential of 321 TWh is estimated in Brazil, which corresponds to 17% of the total electricity consumption in the horizon considered (2050). Given that the building sector is currently responsible for around 50% of total electricity consumption in Brazil, it is estimated that the potential for energy efficiency in the building sector will be around 161 TWh by 2050. The bases for estimating the energy efficiency potential in the slow digitalization scenario are described in section 2.7 (item 2.7.3) of this chapter.

[20] According to data contained in the National Energy Plan 2050 (Brazil, 2002, p. 25), the average rate of 1.8% p.a. is defined for the period 2022-2032, based on economic stagnation, repeating the GDP growth rate in the period 2006-2015.

Digital solution	Design	Construction	Operation	Renovation	Demolition
Building Information Modeling (BIM)					
Building Energy Modeling (BEM) Urban Energy Modeling (UBEM)					
Computational fluid dynamics (CFD)					
Simulation of natural and artificial lighting					
Energy Portfolio Management Systems					
Software for Life Cycle Assessment (LCA)					
3D printing					
Augmented Reality					
Blockchain					
Agile Management Software					
Building Management System (BMS)					
Smart Sensors, Actuators, and Switches					
Addressable Digital Lighting Interface (DALI)					
Smart Facades and other systems					
Virtual assistants					
Smart apps and controls					
Smart sockets and chargers for electric vehicles					
Smart electrical and electronic equipment connected to the grid					
Demand response applications, awareness and gamification					
Cloud Computing					

Picture 2.9 – Digital solutions implemented by life cycle phase in scenario A – Slow digitalization. **Source: [2, 57, 58].**

portfolio management systems are widely used to assist the correct sizing of photovoltaic solar systems and other local renewable energy generation systems, as well as natural gas cogeneration systems.

Thermoenergetic simulation and lighting technologies remain focused on niche markets and applied fundamentally to renovations (whose design possibilities are more restricted).

Sensors, actuators and intelligent switches associated with building management systems (BMS) are widely used in corporate commercial buildings and in part of public buildings, but not always in the best way, requiring periodic consultancies for retrocommissioning. Systems equipped with artificial intelligence are gradually being installed and, consequently, greater autonomy, opening space for consultancies that provide remote resource management services (mainly electricity) in buildings. In this context, the digital light address interface (DALI) technology now presents more tangible benefits and consequently is more widely adopted [2].

Some technologies are very close to the turning point towards massification in the operation phase, but the barriers of high implementation costs and lack of incentives still retain their capillarization potential.

Trajectory 2033-2050

In the 2033-2050 trajectory, the situation of economic stagnation persists, hindering the advance of investments in digitalization in the most diverse sectors of the economy, including construction. Economic growth rates remain low in the period, still around 1.8% a year. Public policies and instruments to promote digitalization in the building sector partially induce digitalization in the sector, restricting itself to initiatives in public buildings. Although limited to public buildings, these initiatives achieve the expected results by the 2050 horizon.

Numerous opportunities continue to arise during the period to make the use of energy efficient resulting from digitalization in the building sector, due to its representativeness in the total consumption of energy and especially of electricity. Energy efficiency labeling remains mandatory for public buildings of the direct, municipal and foundational public administration, however, depending on the results of the regulatory impact analysis in the first decade, it expands to other types, as well as to the design and reform phases of buildings.

In the 2033-2050 trajectory, the opportunities to increase energy efficiency through digitalization in the building sector are partially exploited and the results show promising for future replication. However, challenges remain in the articulation of energy efficiency policies and mechanisms that still hinder the integration of governance structures to optimize the allocation of existing resources, aiming at the full use of these opportunities.

The modernization of the electricity sector in the country remains at a moderate pace in the period from 2032 to 2050, due to the relative use of incentives for distributed generation and energy commercialization. However, the expansion of demand management continues at a slow pace. With regard to housing public policies, given the permanence of the housing deficit in the period, the use of digital solutions in housing of social interest (HIS) and the potential increase in energy efficiency are considered aspects of lesser relevance also in this trajectory, evolving little in relation to first decade.

The maturity phase of the technical standardization and regulatory processes applicable to digitalization and energy efficiency in buildings can be considered under development, as initiatives in Brazil seek to align with successful standardization and regulation initiatives in other countries. The level of qualification of skilled labor remains low until the 2050 horizon. Users' behavioral patterns also do not evolve towards a culture favorable to energy efficiency and the use of digital solutions in buildings during this period. Most users are indifferent and do not yet recognize the benefits of digitalization in buildings, which include reduction of electricity costs, greater comfort and safety, among other benefits.

The implementation of digital solutions in the design, construction, operation and renovation phases of buildings, as mapped in Picture 2.9, evolves in its natural course in the period. Digitalization costs in this sector are still high until the 2050 horizon, contributing to the implementation of digital solutions continuing autonomously and at a slow pace, with induction by the State limited only to initiatives in public buildings. As a result of the slow pace of digitalization in the sector, the potential for energy efficiency is low, at levels below 10% of the total 161 TWh[21] until 2050.

Alongside the implementation of digital solutions in the building sector in Brazil in the 2050 horizon, new digital technologies applicable to the building sector, in addition to those mapped in Picture 2.9, have been developed at a global level and should be included in scenarios with longer horizons.

Scenario B – Moderate digitalization

Philosophy

Digitalization in the building sector in Brazil is implemented at a moderate pace, being induced by the State in public, commercial and service buildings, through regulatory instruments for digitalization and energy efficiency. Public housing policies include mechanisms aimed at increasing energy efficiency and digitalization in housing of social interest, with emphasis on digital technologies of transversal application. Digital solutions are implemented at all phases of the life cycle of buildings, with the increasing participation of private investments. The energy efficiency potential resulting from moderate digitalization reaches levels of 20 to 30% of the total 161 TWh by 2050[22].

[21] In the "Expansion Challenge" scenario of the National Energy Plan 2050, an energy efficiency potential of 321 TWh is estimated in Brazil, which corresponds to 17% of the total electricity consumption in the horizon considered (2050). Given that the building sector is currently responsible for around 50% of total electricity consumption in Brazil, it is estimated that the potential for energy efficiency in the building sector will be around 161 TWh by 2050. The bases for estimating the energy efficiency potential in the slow digitalization scenario are described in section 2.7 – item 2.7.3 of this chapter.

[22] See footnote 15. The bases for estimating the energy efficiency potential in the moderate digitalization scenario are described in section 2.7 – item 2.7.3 of this chapter.

Trajectory 2022-2032

In the 2022-2032 trajectory, a picture of moderate economic growth is observed, favoring to a certain extent investments in digitalization in the most diverse sectors of the economy, albeit at an equally moderate pace. Economic growth rates of around 2.8% a year[23] are recorded. In this first decade, the implementation of digital solutions in buildings has been induced by the State in public, commercial and service buildings, through regulatory instruments for digitalization and energy efficiency.

Investments in digitalization with the growing participation of private capital take place in various sectors of the economy, including construction. Governance mechanisms aimed at integrating the various institutional and regulatory instruments for digitalization, energy efficiency and housing are beginning to drive the adoption of digital technologies in the aforementioned building typologies.

Numerous opportunities arise for the efficiency of energy use resulting from digitalization in the building sector, which are exploited in some way, but not entirely due to the existence of some barriers, such as the low level of qualification of specialized labor and the obligation to energy efficiency labeling be limited to the design and renovation phases. As a result, there is a moderate growth in the market for efficient buildings in the 2022-2032 trajectory.

The regulation for the modernization of the electricity sector in the country continues with promising results, as incentives for distributed generation have been used with wide scope in the country. However, the effectiveness of incentives for the commercialization of energy and the expansion of demand management is considered moderate for both focuses of modernization. Public housing policies include mechanisms aimed at increasing energy efficiency and digitalization in social housing (HIS), with emphasis on digital technologies of transversal application. These are aspects considered strategic in PlanHAB 2040 and some goals defined in this Plan have been achieved, largely through the formation of public-private partnerships.

The technical standardization processes and regulations applicable to digitalization proceed at different phases of development, but not in the desired agility. The level of qualification of specialized labor remains low, but several educational institutions at the most diverse levels are beginning to mobilize in this first decade to expand the offer of vocational courses specialized and update the curricula in higher education. There are changes in the behavioral patterns of users and the culture of users regarding energy efficiency and sustainability of buildings evolves to favor. Users already realize some benefits of using digital solutions, especially the reduction of electricity costs, but concerns persist regarding cyber attacks.

With digitalization taking place at a moderate pace in the building sector, the implementation of several digital solutions available as mapped in Picture 2.10 is observed. The offer of digital solutions in the country can be considered average in this decade, with a relative reduction in the costs of digitalization in the building sector, due to the efforts to integrate and effectiveness of public policies and instruments aimed at energy efficiency, housing and digitalization.

Cloud computing evolves rapidly and acts as an enabler of virtually every digital solution available at varying degrees of maturity. It helps provide security infrastructure, which is gradually augmented by the still punctual use of Blockchain. Building Information Modeling reaches maturity in the design, construction and renovation phases, partly stimulated by the BIM BR Strategy, but mainly by improving the standardization of construction elements and the dissemination of BIM libraries among suppliers. Although it is already beginning to be used in the other phases, mainly in the operation of new and renovated federal public buildings from 2024, it is not yet widely used by the market in general. Although the technology is already available, there are still few cases suitable for use in the operation phase. With energy costs constantly rising and the gradual migration of the electricity sector to the provision of energy services and energy security, the escalation of distributed generation remains, so that energy portfolio management systems are widely used to assist the correct sizing of photovoltaic solar systems and other local renewable energy generation systems, as well as natural gas cogeneration systems.

Thermoenergetic simulation technologies can be better integrated with BIM from the automatic development of layers (layers) representing the thermal zones and the development of specific modules. Thermoenergetic simulation and lighting software evolve and become easier to manipulate, expanding their adoption as tools to aid project conception (in the design and renovation phases).

The appeal of sustainability gradually increases and the demand for decarbonization makes life cycle assessments more important, so that inventories and software offerings are offered as a service, at a lower cost and are widely used in the construction, renovation phases and demolition, fostering the circular economy. This movement is increased by the application of Blockchain in the production chain of construction materials, which allows enormous precision in the quantification of emissions and energy costs embedded in the entire life cycle of the products and assists decision-making on reuse or recycling in the renovation phases and demolition.

[23] According to the estimate of the annual GDP growth rate, which appears in the "Expansion Challenge" scenario of the National Plan for Energy 2050 (Brazil, 2020, p. 22 – Picture 7).

Digital solution	Design	Construction	Operation	Renovation	Demolition
Building Information Modeling (BIM)					
Building Energy Modeling (BEM) Urban Energy Modeling (UBEM)					
Computational fluid dynamics (CFD)					
Simulation of natural and artificial lighting					
Energy Portfolio Management Systems					
Software for Life Cycle Assessment (LCA)					
3D printing					
Augmented Reality					
Blockchain					
Agile Management Software					
Building Management System (BMS)					
Smart Sensors, Actuators, and Switches					
Addressable Digital Lighting Interface (DALI)					
Smart Facades and other systems					
Virtual assistants					
Smart apps and controls					
Smart sockets and chargers for electric vehicles					
Smart electrical and electronic equipment connected to the grid					
Demand response applications, awareness and gamification					
Cloud Computing					

Picture 2.10 – Digital solutions implemented by life cycle phase in scenario B – Moderate digitalization. **Source: [2, 57, 58].**

Sensors, actuators and intelligent switches associated with building management systems (BMS) are widely used in corporate commercial buildings and in part of public buildings, but not always in the best way, requiring sporadic consultancies for retrocommissioning. Systems equipped with artificial intelligence are gradually being installed and, consequently, greater autonomy, opening space for consultancies that provide remote resource management services (mainly electricity) in buildings. In this context, DALI technology now presents more tangible benefits and, consequently, is more widely implemented.

Electric vehicles become more accessible and the infrastructure for charging and information exchange evolves in tow, making sockets for charging electric vehicles common, although still unidirectional flow.

In homes and small businesses, digitalization advances at greater pace with the popularization of the Internet of Things and, consequently, of intelligent applications and controls, as well as the use of virtual assistants for the control of intelligent equipment. Old equipment gains a layer of intelligence with the massive adoption of smart outlets.

Several technologies are approaching the operational phase, but the implementation cost barrier and lack of incentives still retain their capillarization potential.

Trajectory 2033-2050

In the 2033-2050 trajectory, a picture of moderate economic growth remains, with an advance in investments in digitalization in the most diverse sectors of the economy, including construction. Economic growth rates are around 3.1% a year[24] in this period. Digitalization in the building sector continues at a moderate pace in the country, being induced by the State in public, commercial and service buildings, through the integration of some regulatory instruments for digitalization and energy efficiency.

During this period, the opportunities for efficiency in the use of energy resulting from digitalization in the building sector intensify, due to its representativeness in the consumption of electricity in the country and the framework of political stability and moderate growth of the economy. Energy efficiency labeling remains mandatory for all types of buildings, but covers some phases of the life cycle of buildings (design and renovation). The favorable results of the regulatory impact analysis of mandatory requirements for all types of buildings in the first decade expanded the benefits of labeling in the period 2033-2050. Even with some favorable factors for the heating of the efficient building market, moderate growth is observed in the period 2033-2050.

The modernization of the electricity sector in the country continues during this period, with incentives for distributed generation being used with a wide scope in the country. On the other hand, the effectiveness of incentives for the commercialization of energy and the expansion of demand management remains moderate for both focuses of modernization. Public housing policies continue to encourage energy efficiency and digitalization in housing of social interest (HIS), with an emphasis on digital technologies of transversal application. Several goals defined in PlanHAB 2040, referring to the use of transversal digital solutions and energy efficiency, have been achieved with consequences for the decade 2040-2050.

The technical standardization processes and regulations applicable to digitalization continue in this period with some progress in terms of agility, but are still at different phases of development. Although the level of qualification of specialized labor remains low, several educational institutions at the most diverse levels are beginning to offer specialized vocational courses and update the curricula in higher education. Changes in users' behavioral patterns regarding energy efficiency and building sustainability evolve into a culture favorable to these issues. Users realize some benefits of using digital solutions in buildings, especially the reduction of electricity costs. Concerns regarding cybersecurity are mitigated, as new digital solutions to combat cyberattacks are being adopted.

Digitalization in the building sector, driven by economic growth, increased public and private investments, and the induction of the State, continues to be implemented at a moderate pace in the period 2033-2050. Digital solutions, mapped in Picture 2.10, are implemented at all phases of the building life cycle, with the increasing participation of private investments. The energy efficiency potential resulting from digitalization reaches levels of 20 to 30% of the total 161 TWh by 2050[25].

Scenario C – Fast digitalization

Philosophy

Digitalization in the building sector is implemented at a rapid pace in the country, being strongly induced by the State, with broad participation of private investments and accelerated adoption of digital technologies. It covers all types of buildings, due to the effective integration between the various institutional and regulatory mechanisms aimed at digitalization, energy efficiency and housing. Many commercially available digital solutions are adopted at all phases of the building life cycle as early as the first decade. The energy efficiency potential resulting from fast digitalization reaches levels of 30 to 40% of the total 161 TWh[26] by 2050.

Trajectory 2022-2032

In the first decade, economic growth rates of around 2.8% per year[27] were registered, with intensification of international agreements, some of which were of interest to issues related to climate change and the diffusion of digital technologies. The participation of the building sector in the total consumption of energy and especially of electricity leads the State to improve existing mechanisms of energy efficiency and digitalization policies and to broadly induce digitalization in this sector.

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[24] According to the estimate of the economic growth rate contained in the “Expansion Challenge” scenario of the National Plan of Energy 2050 (Brazil, 2020, p. 22 – Picture 7).

[25] In the “Expansion Challenge” scenario of the National Energy Plan 2050, an energy efficiency potential of 321 TWh is estimated in Brazil, which corresponds to 17% of the total electricity consumption in the horizon considered (2050). Given that the building sector is currently responsible for around 50% of total electricity consumption in Brazil, it is estimated that the potential for energy efficiency in the building sector will be around 161 TWh by 2050. The bases for estimating the energy efficiency potential in the moderate digitalization scenario are described in section 2.7 – item 2.7.3 of this chapter.

[26] See footnote 19. The bases for estimating the energy efficiency potential in the rapid digitalization scenario are described in section 2.7 – item 2.7.3 of this chapter.

[27] According to the estimate of the economic growth rate contained in the “Expansion Challenge” scenario of the National Plan of Energy 2050 (Brazil, 2020, p. 22 – Picture 7).

Public and private investments in digitalization take place in various sectors of the economy, including construction. The effective integration between the various institutional and regulatory mechanisms focused on digitalization, energy efficiency and housing drives the accelerated adoption of digital technologies available in all types of buildings.

In view of the representativeness of the building sector in the total consumption of energy and especially of electricity, there are numerous opportunities to make energy use efficient through digitalization in the building sector, which are used in the vast majority. These positive results are attributed to the framework of political stability and moderate economic growth experienced in this decade. Energy efficiency labeling is mandatory for all types of buildings, covering the design, operation and renovation phases. The favorable results of the regulatory impact analysis of mandatory requirements for all types of buildings increased the benefits of labeling in this decade, due to the greater scope of the instrument. As a consequence, all of these factors led to the warming of the market for efficient buildings in the 2022-2032 trajectory.

The regulation for the modernization of the electricity sector in the country is effective, insofar as the incentives for distributed generation and the commercialization of energy have already been widely used in this decade. Demand management expansion is also taking place at a rapid pace, as expected. With regard to public housing policies, the use of digital solutions in social housing (HIS) and the potential increase in energy efficiency are considered relevant aspects in PlanHAB 2040 and promising results have been achieved. The main bottlenecks of the housing sector in the country, mapped in 2022, have been addressed in this decade, with the participation of the actors involved with the theme in the country and the formation of public-private partnerships.

Digitalization in the building sector during this period has been driven by greater agility in the technical standardization and regulatory processes applicable to digitalization and by the significant improvement in the level of qualification of specialized labor. Educational institutions at the most diverse levels are mobilizing in this first decade to expand the offer of specialized vocational courses and update the curricula in higher education. They are combined with these factors that positively impact the acceleration of digitalization in the building sector, changes in the behavioral patterns of users. The culture regarding energy efficiency and sustainability of buildings evolves towards favorable attitudes on the part of users, who already perceive benefits from the use of digital solutions in buildings. They consider benefits in their decisions such as reduction of electricity expenses, greater safety and comfort. Despite these favorable behavioral changes, users' concerns regarding cyber attacks persist in this decade.

With the rapid digitalization in the building sector already in this first decade, it is observed that the available digital solutions are implemented, as shown in Picture 2.11.

The offer of digital solutions in the country can be considered high in this decade and the costs of digitalization in the low-rise building sector, due to the integration and effectiveness of public policies and instruments aimed at energy efficiency, housing and digitalization.

Cloud computing evolves rapidly and acts as an enabler of virtually every digital solution available at varying degrees of maturity. It helps provide security infrastructure, which is gradually augmented by the massive use of Blockchain. Building Information Modeling reaches maturity throughout the life cycle of buildings, partly stimulated by the BIM BR Strategy, but mainly by improving the standardization of construction elements, the dissemination of BIM libraries among suppliers and the evolution of integrations between environments Common Data Environment (CDE) and several other technologies, which enables the use of BIM as a hub for controlling information and technologies.

Thermoenergetic simulation, lighting and CFD technologies are fully integrated with BIM and evolve becoming easier to manipulate, expanding their adoption as tools to aid project conception (in the design and renovation phases), as well as for adjustments in operation (except CFD).

The appeal of sustainability gradually increases and the demand for decarbonization makes life cycle assessments more important, so that inventories and software offerings are offered as a service, at a lower cost and are widely used in all phases of construction, fostering the circular economy. This movement is increased by the application of Blockchain in the production chain of construction materials, and in the operation of buildings, which allows enormous precision in the quantification of emissions and energy costs embedded in the entire life cycle of products and assists decision-making on reuse or recycling in the renovation and demolition phases.

The advancement of additive manufacturing makes it common to use 3D printing of customized construction elements and complex mechanisms, facilitating the adoption of dynamic facades and several other elements, both in the construction phase and in the operation phase, enabling the manufacture of parts on demand in replacement those that have defects or wear and tear. Large 3D printing also evolves and is used for the construction of homes, residential complexes, and social housing.

Digital solution	Design	Construction	Operation	Renovation	Demolition
Building Information Modeling (BIM)					
Building Energy Modeling (BEM) Urban Energy Modeling (UBEM)					
Computational fluid dynamics (CFD)					
Simulation of natural and artificial lighting					
Energy Portfolio Management Systems					
Software for Life Cycle Assessment (LCA)					
3D printing					
Augmented Reality					
Blockchain					
Agile Management Software					
Building Management System (BMS)					
Smart Sensors, Actuators, and Switches					
Addressable Digital Lighting Interface (DALI)					
Smart Facades and other systems					
Virtual assistants					
Smart apps and controls					
Smart sockets and chargers for electric vehicles					
Smart electrical and electronic equipment connected to the grid					
Demand response applications, awareness and gamification					
Cloud Computing					

Picture 2.11 – Digital solutions implemented by life cycle phase in scenario C – Fast digitalization. **Source: [2, 57, 58].**

With energy costs steadily rising and the gradual migration of the electricity sector to the provision of energy services and energy security, the escalation of distributed generation remains, so that energy portfolio management systems are widely used to assist correct sizing and management of photovoltaic solar systems and other local renewable energy generation systems, as well as natural gas cogeneration systems, both on the scale of the building and on the scale of the districts and are largely supported by the use of Blockchain technology in the certification of origin of each asset of energy and in its numerous transactions between various stakeholders. Still in the context of the regulation of the electricity sector and its opening process, demand response, awareness raising, and gamification applications are rapidly evolving and are being widely used, promoting energy efficiency in a more playful way and inserting it into general culture.

Intelligent sensors, actuators and switches associated with building management systems are widely used in corporate commercial buildings of public buildings, with greater input from artificial intelligence and more autonomous systems, which begin to assume the function of exchanging information automatically via Blockchain, backed by specific smart contracts. Electric energy storage systems and electric vehicles become more accessible and the infrastructure for charging and information exchange evolves in tow, making two-way sockets for charging electric vehicles common.

In homes and small businesses, digitalization advances at greater pace with the popularization of the Internet of Things, including white goods appliances and, consequently, of intelligent applications and controls, as well as the use of virtual assistants for the control of intelligent equipment. Old equipment gains a layer of intelligence with the massive adoption of smart outlets.

Trajectory 2033-2050

In the 2033-2050 trajectory, a picture of moderate economic growth remains, boosting the advance of investments in digitalization in the most diverse sectors of the economy, including construction. Economic growth rates are around 3.1% a year[28]. Digitalization in the building sector during this period continues at a rapid pace in the country, being strongly induced by the State, with broad participation of private investments and accelerated adoption of digital technologies.

Numerous opportunities continue to emerge during the period for efficiency in the use of energy resulting from digitalization in the building sector, due to its representativeness in the total consumption of energy and especially of energy and the framework of political stability and moderate growth of the economy. Energy efficiency labeling remains mandatory for all types of buildings, covering the design, operation and renovation phases. The favorable results of the regulatory impact analysis of mandatory requirements for all types of buildings in the first decade expanded the benefits of labeling in the period 2033-2050. All of these factors contribute to the efficient buildings grow in the period 2032-2050, reaching levels higher than those experienced in the first decade.

The modernization of the electricity sector in the country continues during this period, maintaining the incentives for distributed generation and the commercialization of energy, which were already being used with wide scope in the country in the decade 2022-2032. Demand management expansion also continues at a rapid pace, as planned for the long term. The use of digital solutions in social housing (HIS) and the potential increase in energy efficiency in buildings in general are strategic focuses in PlanHAB 2040. This Plan has been implemented with the participation of the various actors involved with the theme in the country, with impacts on the digitalization of the sector until the horizon of 2040. In the following decade, new challenges are identified and considered in the review of PlanHAB 2040. Digitalization and energy efficiency in buildings are strategic themes that remain on the long-term agenda of the Ministry of Regional Development.

Digitalization in the building sector continues to be driven by the agility in the technical standardization processes and regulations applicable to digitalization, as well as by the improvement of the level of qualification of specialized labor, observed already in this decade. In addition to these factors that stimulate rapid digitalization in the building sector, changes in users' behavioral patterns are reflected in a culture favorable to energy efficiency and building sustainability. Behavioral changes favorable to digitalization can be observed and continue to drive the growth of the efficient buildings market. Cybersecurity issues are a constant concern, but they are addressed in this period multidisciplinarily. The very advancement of some digital technologies favors the continuous fight against cyber attacks.

With the rapid digitalization in the building sector already in the period 2022-2032, the massification of digital technologies is observed, driven by economic growth and increased public and private investments and by the integration and effectiveness of public policies and instruments aimed at efficiency energy, housing and digitalization. Commercially available digital solutions are adopted at all phases of the life cycle of buildings from the first decade. The energy efficiency potential resulting from digitalization reaches levels of 30 to 40% of the total 161 TWh[29] by 2050.

2.8 Analysis of the barriers to the implementation of digitalization in the building sector in Brazil and strategic implications

The following is a set of barriers to the implementation of digitalization in the building sector in Brazil, identified by the team based on document analysis and semi-structured interviews conducted with specialists during the month of November 2021. The barriers were classified into four groups:

i. Institutional;
ii. Marketing and financial;
iii. Techniques;
iv. Behavioral and skilled labor skills

2.8.1 Institutional barriers

IB1 – Implementation of several sectoral public policies in an uncoordinated manner, without synergy between the competent bodies

The implementation of energy efficiency policies and mechanisms involves a complex chain that requires coordination between several sectoral policies, with objectives different from energy efficiency policies, but

[28] According to the estimate of the economic growth rate contained in the “Expansion Challenge” scenario of the National Plan of Energy 2050 (Brazil, 2020, p. 22 – Picture 7).

[29] In the “Expansion Challenge” scenario of the National Energy Plan 2050, an energy efficiency potential of 321 TWh is estimated in Brazil, which corresponds to 17% of the total electricity consumption in the horizon considered (2050). Given that the building sector is currently responsible for around 50% of total electricity consumption in Brazil, it is estimated that the potential for energy efficiency in the building sector will be around 161 TWh by 2050. The bases for estimating the energy efficiency potential in the rapid digitalization scenario are described in section 2.7 – item 2.7.3 of this chapter.

correlated. In addition, there are situations in which the coordination of policies and actions involving the federal, state and municipal levels or the articulation between different agents, such as the government, energy end consumers, and financing agents [1], is required. Institutional complexity and the current level of articulation of energy efficiency policies and mechanisms hinder the integration of governance structures for the execution of policies and optimization in the allocation of resources.

IB2 – Retraction of investments in ST&I with an impact on the digitalization of sectors of the economy

The downturn in Brazilian public investments in ST&I worsened from 2020 with the Covid-19 pandemic, when all the main budget items of the Ministry of Science, Technology and Innovation (MCTI) were reduced, including the National Fund for the Development of Science and Technology (FNDCT) and the resources from the National Council for Scientific and Technological Development (CNPq) and the Financier of Studies and Projects (Finep). Public investment in ST&I is at lower levels than those observed 20 years ago. The instability of resources and the consequent discontinuity of ST&I projects and actions in the most diverse areas may result in the delay of important research for the country in general, and in particular in ST&I areas, whose results would boost digitalization in various sectors of the economy, including the buildings.

Therefore, the path to increasing innovation in Brazil is through the optimization of public investment and the expansion of private investment, which can be achieved through the application of stimulus instruments and the increase of legal certainty, in the form of legal and regulatory frameworks that foster investment.

IB3 – Standardization and regulatory processes do not keep pace with the evolution of digital technologies

The rapid pace of development and supply of digital solutions causes the market to be out of step with the technical standardization processes at international and national level, as well as with those of regulation, which also have a long way to go until the implementation of technical regulations and legal instruments. This mismatch hinders the adoption of some digital solutions in the most diverse sectors, including the building sector, as the expected benefits of standardization may not materialize due to the accelerated pace of digital innovations.

A recent study, coordinated by the Center for Management and Strategic Studies (CGEE) on the perception of Brazilian companies regarding technical standardization for Industry 4.0 in the country sought to understand what were the priorities perceived by the responding companies regarding participation in standardization in the themes of Industry 4.0; identify the willingness of companies to participate directly in international and national technical standardization bodies of the following standardization bodies: ISO, IEC, ITU-T, ABNT and ANATEL; and verify whether companies already participate in the standardization process and its main difficulties [77]. Among the five digital technologies that companies judged that standardization plays an important role in its adoption in Brazil were:

- **i.** Internet of Things (52% of companies);
- **ii.** Intelligent Sensors (47%);
- **iii.** Artificial Intelligence (32%);
- **iv.** Cloud Computing (31%);
- **v.** Advanced robotics (29%).

From the point of view of the contribution of standardization to digital transformation in Brazil, the study recommends that national standards be the adoption of international standards and that Brazil actively participate in the development of international standards identified as priorities, so that the Brazilian vision be taken into account, how much so that Brazilian companies gain first-hand knowledge of these technologies, acquiring and mastering it through this participation in its discussion and construction [77].

IB4 – Some of the representatives of the building sector in Brazil resist rules and regulations and their applications

The building sector is composed of several companies and agents such as developers, construction companies, project offices, building administrators, users, suppliers and manufacturers of materials, and service providers. Each actor brings with it its own diversity, whether in size, specific objectives, financial conditions and specific challenges, or in the affinity of adopting technologies in their daily lives. In general, the industry is considered reactive to changes, preferring the usual way of doing business, one of the forms of materialization of this characteristic is the resistance to standardization and standardization that associated with an environment of high informality leads to a low level of its implementation. Mercosur neighboring countries with much smaller industries are at a more advanced stage. With regard to digitalization, this barrier makes it very difficult to adopt digital solutions that need consistent data and information to maximize their benefits at all phases of the life cycle of a building. It is noted that part of the entrepreneurs in the sector have participated proactively in government initiatives in the area.

2.8.2 Market and financial barriers

MB1 – Lack of specific credit lines for the implementation of digital solutions in buildings

Despite the existence of specific credit lines for efficient buildings or linked to certifications, there are no specific lines for the digitalization of buildings in Brazil. However, the National Bank of Economic and Social Development () supports, through FINEM (Financing for Projects) – Environment – Energy Efficiency, projects for the energy efficiency of buildings, focusing on air conditioning, lighting, enveloping and distributed generation, including cogeneration, for new or existing units (renovation). Since is an institution focused on financing development activities, the release of funds depends on the analysis of several factors related to credit risk, which ends up bureaucratizing the process [78]. There are other products on the market, but with a specific focus on building efficiency and not on building digitalization; an example is the Casa Azul Caixa Econômica Seal.

MB2 – High initial costs of adopting technological solutions in buildings by pioneers

As in any market, pioneers are willing to acquire new technologies, even if they risk buying a product that has not yet been approved by the market and that it is more expensive. The building sector may have greater challenges in relation to the adoption of certain technologies, since their initial costs may be prohibitive for a certain portion of the population of Brazil, which faces problems such as precarious housing conditions and which compromises a large part of the income with rent.

MB3 – Low purchasing power of users of some types for the adoption of digital solutions

Brazil has a great social inequality that has been increasing in recent years. In addition, the vast majority of Brazilian families have very low incomes, when compared to those in developed countries. This data can be corroborated by the high housing deficit existing in the country. Therefore, the low purchasing power of some building users may be a barrier to the adoption of digital solutions in the country, particularly in social housing (HIS).

MB4 – Low availability of information on the potential and costs of energy efficiency opportunities

The availability of data regarding the final consumption profile, its uses and energy efficiency potential and its costs requires information with a degree of stratification at the sectoral level, so that they can provide inputs for the periodic evaluation of policies and mechanisms to promote energy efficiency and, therefore, of its effectiveness as an instrument to promote the insertion of this resource as an alternative to meet energy demand, including contributing to the evaluation of the effectiveness of the application of financial resources of energy efficiency programs in the country. This is fundamental to map existing barriers, in order to prioritize actions to be undertaken to boost the use of the potential to increase energy efficiency by building type.

MB5 – Opportunity costs (need for renovations) not used for renovations focusing on energy efficiency and digitalization

Buildings just over 15 years old may require changes to their systems to be carried out [79]. However, many buildings in the country are renovated over much longer periods. With the rapid evolution of digital technologies, many opportunities to improve building performance can be wasted during this period, which tends to be very long.

MB6 – Impact of the costs of implementing digitalization in Social Interest Housing (HIS)

Profit margins for construction companies investing in HIS programs are quite narrow. Thus, the feasibility parameters for the adoption of any differentiated solutions need to be defined in such a way that they do not impact the CAPEX of the project. In theory, there would be a second alternative that would require a paradigm break, that is, to transfer risk to financial institutions. The interventions would need to demonstrate with certainty that the reduction in OPEX could increase the financing margins, which is currently set at R$ 7,000.00, according to Decree No. 10,600, of January 14, 2021.

The Energy Efficiency in Sustainable Urban Development Project (EESUD) prepared a proposal for a financing mechanism, based on a Revolving Credit Guarantee Fund, so that, with the reduction of interest rates, construction companies can implement energy efficiency measures in housing units of social interest in Brazil (HIS). The guarantee provision aims promote the reduction of the interest rate, contributing to the equalization of the payment capacity in relation to the installment, compensating, to some extent, the increase in costs to provide housing with energy efficiency. In this sense, it encourages the expansion of the energy efficiency housing market and, through scale gains, the gradual reduction of associated costs. The option for the guarantee mechanism allows the turnover of the use of the funds raised, expanding the potential results.

The construction of history (track record) and databases generated from the provision of the guarantee is another expected benefit, which, in turn, contributes to greater adherence by the financial sector and increases efficiency in the pricing of the spread, allowing its reduction, once again favoring the equalization of costs. The wide range of affordable credit, within the scope of the Housing Financing System (SFH), is a key factor for the institution of this mechanism.

The target sector of households was defined considering the ability to bear some additional cost resulting from the incorporated energy efficiency, despite the efficiency already providing medium and long-term savings. The minimum energy efficiency package (s) to be defined shall take into account this ability to support price increases, in a manner consistent with the desired effects in terms of minimum reduction in emissions from such dwellings.

MB7 – Lack of precise definition of roles and responsibilities regarding the use and warranty of equipment incorporated into the building

One of the biggest complaints from developers relates to the insecurity of delivering equipment along with housing units. This occurs because, in the event of problems related to these equipment, the liability for the burden of exchange or repair is not clearly defined and the market practice is to always resort to the developer. The lack of clarity regarding these responsibilities makes it very difficult to implement new digital solutions, as it creates a paradox in which those who are responsible for building and could implement new technologies, do not do so because they do not earn gains compatible with the new responsibilities and risks you need to take.

2.8.3 Technical barriers

TB1 – Non-friendly interfaces hindering the adoption of digital solutions

Commercial research on the use of digital solutions analyzes mentions the difficulty of using these technologies as one of the inhibiting factors of their wide adoption. One of the causes pointed out is the unfriendly interfaces, which generate frustrating experiences for the user and that increase resistance to use and even blocking. Human-centered projects can minimize or even eliminate this type of barrier, as they require the exercise by suppliers of digital solutions to design them taking into account the characteristics of use from the perspective of users.

TB2 – Lack of internet infrastructure to provide wide and quality access for the promotion of digitalization in buildings

Democratic access to the internet is still one of the major obstacles to the massification of digital technologies in the building sector. According to data from the Brazilian Institute of Geography and Statistics (IBGE), in 2019 almost 40 million people in Brazil had no connection with the digital world, a number that represents 21.7% of the population over the age of ten [9].

The 5G auction, which took place in early November 2021, to select operators of connectivity services using the fifth generation of mobile telephony [31], should improve the digital infrastructure. However, in a country with as many inequalities as Brazil, it is important to improve 4G and other networks. The massification of access also demands the intensification of the use of other tools such as Blockchain, which has enormous potential to automate and provide more security for various transactions. It should be noted that democratic access constitutes a major barrier to the dissemination of digitalization as a whole and also in the building sector.

TB3 – Embryonic internship in the country of standardization of processes, materials and equipment in the building sector

The standardization of processes, materials and equipment is so crucial in the digitalization of the building sector, that it has been addressed in this study from various perspectives. Through the Brazilian Habitat Quality and Productivity Program (PBQP-H) [51], a quarterly assessment is carried out on various construction materials. In addition, there is a certification for construction companies and evaluation of innovative and conventional construction systems. Today, only construction companies that undertake housing programs seek this information, but the scope of the Program may cover other constructions.

Despite these efforts, the embryonic stage of standardization in civil construction limits the dissemination of digital technologies in buildings and the interchangeability of solutions among the most diverse agents in this sector. The high level of waste in civil construction could be reduced, as well as the increase in productivity and quality of services and materials in the sector could be boosted, if standardization of processes, materials and equipment in the building sector were at a more advanced stage.

TB4 – Cyber insecurity

Cyber insecurity was addressed from the point of view of the user's concern about the loss of their data. However, another important aspect is the need to develop techniques and technologies that prevent invasions of information and computer systems. According to research by McAfee (2020) [80], in 2020 alone, the losses generated by cybercriminals totaled more than US$ 1 trillion. According to consultancy McKinsey, 60% of executives estimate that technical debt (technological out-of-date) has increased in the last three years [81]. Worse than that, 69% of executives spend up to 20% of their investments on new projects with items associated with downgrading, such as upgrading a database to the minimum version required by Oracle, AWS, or Microsoft clouds. Despite these alarming numbers, the vast majority of companies use less than one-fifth of their annual IT budgets to stay current. Thus, cybersecurity from a technical point of view also constitutes a barrier to be minimized so as not to slow down the pace of adoption of digital solutions, especially in large buildings.

Blockchain technology can be used in smart contracts during the operation, construction, and renovation phases of the building. It enables the tracking of various processes in these phases of the life cycle, such as control of material inventory, labor force, available technologies, and environmental conditions. Through smart contracts, the use of Blockchain technology also guarantees the transparency and security of the transactions carried out, since the data is permanently registered on a platform, allowing all parties to audit the information defined by the contract. This technology is one of the examples of cybersecurity technologies that should become popular in the coming decades to increase quality and reduce excessive costs in cybersecurity, which would hinder the mass adoption of digital solutions in buildings.

TB5 – Adoption of digitalization in existing homes and small businesses/services, as it requires civil works, may make its implementation unfeasible

There are different levels of digitalization that can be implemented in buildings of various types and sizes. Many do not require major interventions, such as smart sockets, intelligent equipment equipped with IoT, smart lamps, some types of sensors, applications and smart displays, for example. Others, however, require specific planning, well-established infrastructure, present requirements regarding electrical grids and telecommunication networks, and interact with other building systems, such as some types of sensors, actuators, meters, frequency inverters, generation and storage systems energy and building management systems, among others. For this second case, in fact, the need for works to implement the technologies is fundamental and may make adoption unfeasible, if this is the sole reason for the intervention. This barrier is closely related to that of untapped opportunity costs for energy efficiency and digitalization.

2.8.4 Behavioral and skilled labor qualification barriers

BB1 – Resistance of the construction sector to new digital technologies in buildings

The construction sector in Brazil has historically been reactive to change, since it operates generally and predominantly with temporary and low-skilled labor, even for conventional construction technologies, adapting only to legal or regulatory restrictions. It is, therefore, an important source of employment and income for a considerable portion of the population with low level of education and technical preparation, generating a political impedance for the reversal of this situation. The cycle is vicious and already harms the sector, as was pointed out by the Brazilian Chamber of the Construction Industry (CBIC) regarding the resumption of projects in 2021 [82]. The breaking of this paradigm could occur from the expansion of the general levels of education and training of the population.

Among the most specialized bands of labor in the sector, such as architects, there is also a cultural resistance to digitalization, considering that in the sector of corporate commercial buildings, in particular, the association between intelligent buildings and the aesthetics of international architecture, whose premises are inadequate for environmental comfort, especially in tropical regions. As a result, they require high use of artificial lighting and air conditioning systems, causing high energy consumption. Added to this is the low data culture of organizations, the difficulty of finding reliable parameters and references, and the low availability of information, and there is a context in which the value of digitalization is not easily perceived [83].

BB2 – Low user confidence regarding the benefits of adopting digital solutions and cybersecurity

Users also have a low perception of value in relation to the benefits of digitalization, either due to the difficulty of use, resulting from the development of products disregarding the opinion of their customers, or due to the eventual dependence on specialized professionals scarce in the market (and, therefore, expensive), whose the benefit of labor is lost in relation to the cost. The lack of success stories and tangible experience, whether in terms of effort savings, comfort gain or financial return also discourages the average consumer from embarking on the path of digitalization.

Despite the increasingly common protection systems, such as firewalls and antivirus, as well as the additional protections offered by cloud computing platforms, the low digital culture also influences cybersecurity, increasing susceptibility to attacks, mainly due to personal factors, such as lack of care in the creation and storage of passwords, lack of information classification protocols and fundamentally susceptibility to scams.

BB3 – Culture of energy efficiency in Brazilian society

In addition to the design of specific and transversal sectoral instruments for the promotion of energy efficiency in the country, mechanisms that encourage actions of active demand management by consumers represent an important part of the equation for reducing energy consumption through efficient use. In this sense, the education component contributes to the perpetuity of the installation of efficient equipment, standards and regulations through the behavior of efficient use of energy by end consumers [1]. However, there is still a lot of confusion between the terms energy conservation, energy efficiency, and rationing, which are often understood as synonyms by a significant portion of the population.

The relatively recent cases of energy insecurity, “blackouts”, low reservoirs and the high cost of electricity resulting from tariff flags undermine the differentiation between terms and reinforce the pejorative approach [1]. It is important to emphasize that the culture indifferent to energy efficiency occurs because it is not possible to perceive its benefits, especially from an economic perspective.

BB4 – Outdated curricula in vocational courses and higher education in relation to the topics digitalization and energy efficiency

The permeability to curricular changes in Brazil is low and time-consuming. For many years, the topic of energy efficiency appeared only as lines of research in *stricto sensu* graduate courses and, currently, it is gradually being included in the full curricula of architecture and some engineering schools, despite being important for the market for more than a decade, being especially present in national and international certifications aimed at the corporate sector. Digitalization is still extremely restricted to niches and to electrical engineering, in the specialty of control and automation, or to telecommunications engineering. The low demand, resulting from the low literacy related to these topics, hinders the supply of specific courses, which impacts on the low availability of specialized labor and, consequently, on their costs. The movement, however, has enormous transformative potential, as it levels knowledge and creates offers with the potential to raise awareness of end users based on the provision of higher quality services. Digital transformation courses and consultancies have proliferated, especially in the last two years, however they have nonspecific content, generally more linked to the discipline of project management.

BB5 – Low supply of professional education and training in building digitalization

The supply of professional education related to the construction sector tends to be low to a large extent because of the low demand, given that the sector employs mainly disqualified labor in exchange for low wages. For comparison purposes, even the core activities of civil construction are supplied based on informal training and unstructured transmission of knowledge based on experience to the detriment of formal training processes. This logic, however, cannot overcome the digitalization theme, whose scope is more complex and with less margin for failure.

The low supply of professional education incurs the shortage of qualified professionals, which feeds back the insecurity of planning and control professionals (such as architects and engineers) and the mistrust of end users.

BB6 – Rapid technological changes make it difficult for the market to keep up to date

The growing offer of solutions and technologies, constantly updated and expanded, in fact requires a continuous learning movement from everyone, which does not always occur naturally, requiring awareness and training, as well as incremental investments in infrastructure and programs, so that they remain updated and used satisfactorily. The increasingly narrow trend of planned obsolescence contributes to aggravate this situation. On the other hand, there is a tendency to offer solutions as services, through cloud computing strategies, as well as the development of user-centered solutions, whose use is self-explanatory, but which are not yet a consolidated reality in the building sector.

BB7 – Greenwashing of buildings

The term “greenwashing” is used to describe the way of communicating erroneous information to consumers, in order to describe a particular product or policy as more favorable to the environment, than it actually is [84; 85]. In the building sector, numerous self-declaration stamps to present environmental advantages began to appear. The recycled product gains value and is mistakenly seen the dissemination of products that call themselves 100% recycled. Paints promise to reduce energy consumption with air conditioning by up to 20% if applied to the roof.

Examples like these deceive the consumer, who, with the purpose of contributing to the preservation of the environment, ends up purchasing a product that does not offer what it informs. The lack of knowledge of both the supplier and the consumer generates the phenomenon of greenwashing, with negative impacts for both.

2.9 Final considerations

This chapter provided analytical and methodological subsidies to build alternative futures regarding the energy efficiency potential resulting from digitalization in the building sector in Brazil, in the horizon 2050. Three different scenarios were presented according to the combination of the expected evolution of the main conditions analyzed during the scenario.

Scenario A described the evolutionary trajectory of digitalization in the building sector in Brazil taking place at a slow pace, with induction by the State limited to public buildings. The adoption of some digital solutions occurs autonomously, following the natural evolution of the market for these technologies in the country. As a result of the slow pace of digitalization in the sector, the potential for energy efficiency is below 10% of the total 161 TWh by 2050.

Scenario B presented the evolution of the implementation of digitalization in the building sector at a moderate pace, with induction by the State in public, commercial and service buildings. Digital solutions are implemented at all phases of the life cycle of buildings, with the increasing participation of private investments. The energy efficiency potential resulting from moderate digitalization reaches levels of 20 to 30% of the total 161 TWh by 2050.

Scenario C advocated digitalization in the building sector taking place at a rapid pace in the country, due to the strong induction by the State, the wide participation of private investments and the accelerated adoption of digital technologies. In this scenario, the energy efficiency potential resulting from rapid digitalization reaches levels of 30 to 40% of the total 161 TWh by 2050.

The three scenarios are equally probable, although the analysis of their trajectories presents different trends of maturation of the constraints, due to the different rhythms of implementation of digitalization in the sector and economic growth frameworks, ranging from stagnation and moderate growth to horizon 2050.

Based on the evolution of the constraints in the three scenarios and the analysis of the barriers to the implementation of digitalization in the building sector in the horizon 2050, Chapter 4 proposes a set of recommendations associated with the barriers, seeking to contribute to the formulation of public policies and actions aimed at digitalization and energy efficiency in the building sector in Brazil and reducing risks in decision-making processes, both in the public and private spheres.

3. Case studies

This chapter aims to describe four digitalization case studies in buildings of different types, located in the national territory, contemplating architectural characteristics, energy efficiency measures, description of digital solutions and data on reducing energy consumption.

The cases portrayed are:

- AQWA Corporate (Rio de Janeiro – RJ) – design and operation phases;
- São Paulo Corporate Towers (São Paulo – SP) – design and operation phases;
- Minha Casa + Sustentável (Rio de Janeiro – RJ) – design phase;
- Gávea Planetarium (Rio de Janeiro – RJ) – renovation and operation phases;
- SICOOB Datacenter (Brasília – DF) – renovation and operation phases.

The description of these cases aims to show the impact of digital technologies on the energy efficiency of the respective buildings, considering the country's climate context. The complexity of data collection stands out, especially in the operation phase, given that most of the identified buildings were designed and built with embedded digital solutions. This makes it difficult to measure energy consumption, before and after the implemented technology and, therefore, the energy efficiency gains derived from these solutions. In this sense, most of the energy savings data presented below refer to estimated savings and not necessarily to measured savings.

3.1 Selection of case studies

Case studies were selected in four phases, as described below.

First phase – Initial survey

The first phase consists of the identification of potential cases of intelligent and efficient buildings from their own files and contact networks of the researchers involved in this work, as well as via internet research. Internet research focused on digital information vehicles, such as architectural and consulting firm websites focused on the area of sustainability and energy efficiency. Initially, we sought to cover all types and phases of the building life cycle, as presented in the Preliminary Report [2], aiming to present a broader overview of the potential of digital solutions in relation to the energy efficiency of Brazilian buildings. However, it was observed that the current state of implementation of digitalization in the country would not cover all types and phases of the life cycle of buildings.

Second phase – Pre-selection

The pre-selection phase consisted of the analysis of all potential cases identified, aiming to select those that would have more in-depth data and information on energy consumption. The recommendations made by the specialists during the semi-structured interviews conducted in the first phase of this study were prioritized. However, factors such as the typology and phase of the building life cycle, in which digital technologies contributed to the increase of energy efficiency, were also adopted as pre-selection criteria, aiming to present greater diversity in the case studies contemplated in this document. Table 3.1 presents the fifteen pre-selected cases, classified according to their location, typology, and phase of the life cycle.

Table 3.1 – Pre-selected cases, classified by location, typology and life cycle phase. **Source: Made by the authors.**

Life cycle phase	Project/Building title	Location	Typology
Project	São Paulo Corporate Towers	São Paulo – SP	Commercial/Corporate
	AQWA Corporate	Rio de Janeiro – RJ	Commercial/Corporate
	Minha Casa Mais Sustentável	Lauro de Freitas – BA	Residential/Social Interest Housing
	Library Padre Eugène Charbonneau*	São Paulo – SP	Serviços/Educational
	Nova Casa CEPEL NZEB	Rio de Janeiro – RJ	Public/Laboratory
Operation	Cidade Nova Administrative Center	Rio de Janeiro – RJ	Commercial/Corporate
	SICOOB Data Center	Brasília – DF	Commercial and Services
	Candelaria Corporate	Rio de Janeiro – RJ	Commercial/Corporate
	São Paulo Corporate Towers*	São Paulo – SP	Commercial/Corporate
	AQWA Corporate*	Rio de Janeiro – RJ	Commercial/Corporate
	Sanofi Headquarters Office*	São Paulo – SP	Commercial and Services
	Insper Building – Institute of Education and Research*	São Paulo – SP	Serviços/Educational
Renovation	Gávea Planetarium*	Rio de Janeiro – RJ	Public/Educational
	Edifício Comendador Yerchanik Kissajikian (CYK)*	São Paulo – SP	Commercial/Corporate

Note: * Presented to GIZ and MME.

Third phase – Validation of pre-selection

As agreed at the follow-up meeting held on November 10, 2021, the list of pre-selected case studies was submitted to the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ), the Ministry of Mines and Energy (MME) and the Ministry of Regional Development (MDR) on 21 November this year. The orientation of the choice of cases based on the energy savings arising from the use of digital technology was sought and several possible candidates were analyzed in more detail.

Fourth phase – Final selection and obtaining information

A thorough survey of the contribution of digital technologies to the energy efficiency of the identified buildings was carried out. The criterion used for the final selection of the case studies was the validation of the information found, either through the exchange of messages/emails with those responsible for the projects/buildings or their availability to participate in recorded interviews. Based on this, the number of case studies to be presented decreased to five. Subsequently, one case was withdrawn due to the absence of disclosure authorization in time, totaling four cases, namely:

- Minha Casa + Sustentável Frei Caneca (Rio de Janeiro – RJ);
- AQWA Corporate (Rio de Janeiro – RJ);
- São Paulo Corporate Towers (São Paulo – SP);
- Gávea Planetarium (Rio de Janeiro – RJ).

3.2 Case study 1 – Minha Casa Mais Sustentável

Minha Casa Mais Sustentável was an initiative that aimed at studies to propose more sustainable and energy-efficient projects. The case presented is of a project in the municipality of Rio de Janeiro – RJ, prepared within the scope of the regulations of the My House My Life Program (PMCMV) [86-90].

Table 3.2 – Case study 1 – Minha Casa Mais Sustentável.
Source: Made by the authors.

Title: Frei Caneca Prototype	Main use: Residential
Municipality: Rio de Janeiro – RJ	Bioclimatic Zone: ZB 8
Neighborhood: Catumbi	Zip Code: 20211-010
Building life cycle phase	Design
Building typology	Residential/Social Interest Housing (HIS)
Digital Technologies used	Building Energy Modeling (BEM)
Reduction in energy consumption (%)	3.13%
Built area (m²)	46.21 m² and 43.46 m² per HU
Participation institutions	National Housing Secretariat – SNH/MDR Eletrobras/Procel Edifica Prourb – Graduate Program in Urban Planning from UFRJ FAU/UFRJ Housing Network Energy Efficiency Network (R3E)/UFV

Architectural features of the project

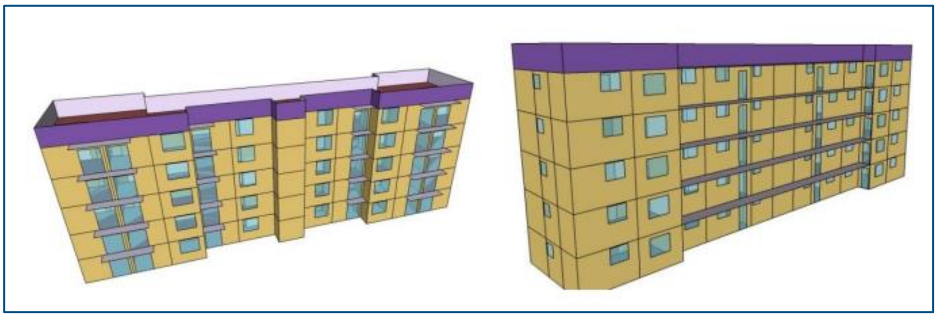
It is an experimental project for the My House My Life Program, located at Rua Frei Caneca, in Catumbi, Rio de Janeiro, RJ. As an alternative to the H-format geometry model, commonly reproduced by the PMCMV construction companies, but which does not favor better insolation and the predominance of winds, in addition to its implementation giving too much value to the use of the car, a study was carried out to propose an alternative solution, in the rectilinear format and in the manner of implementation of the units, aiming to improve thermal comfort and the incorporation of energy efficiency measures.

Picture 3.1 – Concept image of the project proposed for Minha Casa Mais Sustentável. Source: [90].

Energy efficiency initiatives

Through thermoenergetic simulation (BEM) in the design phase, the following design solutions were suggested to improve energy efficiency:

- Orientation of the blocks – larger facades in the Northeast-Southeast direction:
    - Exposure of the environments to the prevailing winds (southeast), combined with the elongated shape of the blocks, to favor natural ventilation;
    - Pressure differential between the two facades that tends to intensify the air flow between the openings;
    - Better orientation of the environments, with bedrooms and living room facing east, bathrooms, kitchen and horizontal circulation to the west;
- Cross ventilation in the unit – typology and frames (scales and door with wicket);
- Inclusion of balconies for shading the facade;
- Increase in the size of the frames to meet the prerequisites of natural lighting;
- Adoption of frames with the possibility of shading without prejudice to lighting and ventilation;
- Thermal insulation of the roof (reflective blanket);
- Installation of solar water heating system;
- The possibility of including a photovoltaic system for power generation for the common areas of the condominiums was also considered.



Picture 3.2 – Geometric model of the proposed project, containing the thermal zones, openings and solar protections of the main façade and back. Source: [90].

Description of digital solutions

The simulation of the thermoenergetic performance of the proposed model aimed to assess the energy efficiency level of each housing unit – HU and of the multifamily building, according to the criteria of the Residential Building BLP and its equivalent in energy consumption. The software that was used was EnergyPlus, version 8.1.03 The calculation of the final energy efficiency level of the HU considered efficiency level A of the water heating system and without bonuses.

Energy savings data

The estimated difference for the annual consumption of the air conditioning system, comparing the original model (type H) and the proposed model, was 2.00 kWh/conditioned area, which is equivalent to 1,776 kWh/year (considering the multifamily building as a whole) or a reduction of 3.13%.

3.3 Case study 2 – AQWA Corporate

AQWA Corporate and São Paulo Corporate Towers (section 3.4) are two commercial ventures with LEED certification, and digital technologies have been used since the conception of the project. The energy efficiency consultancy was carried out by the same company that followed the certification process, the Building Technology Center[30] [91-94].

Architectural features of the project

The development has 22 floors distributed between two buildings, with spaces for offices, commercial stores and public spaces on the ground floor. The parking is divided into five underground levels. The entrance hall of each building was built above the central public square, with views of the port and Guanabara Bay. Three escalators make the connection between the central square and the building's lobbies, in addition to the elevators that take visitors directly to the parking lot. The service and circulation centers were planned so that each floor can be subdivided into up to four different companies. The main structure consists of a concrete slab cast in situ under a metal deck with the lobbies suspended over a steel structure.

Table 3.3 – Case study 2 – AQWA Corporate.
Source: Made by the authors.

Title: AQWA Corporate	Main use: Corporate
Municipality: Rio de Janeiro – RJ	Bioclimatic Zone: ZB 8
Neighborhood: Santo Cristo	Zip Code: 20220-297
Building life cycle phase	Design and Operations
Building typology	Commercial and Services
Digital Technologies used	Building Energy Modeling (BEM) Building Management System (BMS) Lighting simulation
Reduction in energy consumption (%)	15.47%
Built area (m²)	223,000 m²
Participation institutions	Foster Architectural Firm + Partners Tishman Speyer Properties

Picture 3.3 – Photograph of AQWA Corporate.
Source: Disclosure/Diário do Porto.

Energy efficiency initiatives

The following initiatives were designed for the building, with the aim of reducing energy consumption and obtaining the LEED Building Design and Construction Certification:

- Determination of energy efficiency measures through thermoenergetic simulation (BEM) in the design phase;
- Implementation of a building management system (BMS) in the operation phase;
- High-efficiency internal lighting system;
- Glazing with high thermal performance and low solar factor;
- Facade with a negative slope reducing the solar incidence inside the building;
- Centralized air conditioning system consisting of chilled water plant and chillers with high performance at partial loads.

[30] https://cte.com.br/.

Description of digital solutions

Building energy modeling (BEM) was used in the project development phase, primarily in simulations considering aspects related to façade glazing, internal lighting systems and air conditioning systems, thus generating indications of the best configurations possible to achieve higher levels of energy efficiency. The software used to perform the simulations was Energy Plus.

The building management system (BMS) was used in the operation phase of the building, acting on the air conditioning system, which works according to the occupancy schedule of the building to ensure its automatic shutdown, optimizing energy consumption. In addition, the BMS monitors and controls the energy consumption of the common areas of the building to enable operational optimization, and the energy consumption meters are integrated into the monitoring system and installed according to the energy end uses. The possibility of monitoring with the use of BMS also contributes to individualized management, in which tenants have individual meters that allow obtaining consumption data of the occupied space, thus encouraging the conscious use of energy.

Energy savings data

AQWA Corporate is a corporate building designed to be a sustainable Triple A building model in Brazil (Cooling, Lighting and Envelopment). The result accepted by the U.S. Green Building Council was 15.47% annual energy cost reduction in relation to the ASHRAE 90.1-2007 reference model (baseline), awarding four points in the LEED “Energy Efficiency Optimization” credit in Brazil for the LEED BD+C Core and Shell typology. It is important to note that this project was certified with the use of the LEED BD+C Core and Shell V3 Methodology (2009).

3.4 Case study 3 – São Paulo Corporate Towers

Like AQWA Corporate (section 3.3), São Paulo Corporate Towers is LEED certified, and digital technologies have been used since the design's conception [95].

Architectural features of the project

The project was built on a large plot, which has about 19,000 m² of green area, with preserved native trees, which guided the entire landscape project. In it are two corporate towers, in a twisted shape, forming a dynamic composition in the urban landscape; a building that houses the convention center, restaurant and cafeteria, which are incorporated into a staggered basement covered by gardens; and a technical building, where are the equipment and the power generation.

Table 3.4 – Case study 3 – São Paulo Corporate Towers.
Source: Made by the authors.

Title: São Paulo Corporate Towers	Main use: Corporate
Municipality: São Paulo – SP	Bioclimatic Zone: ZB 3
Neighborhood: Vila Olímpia	Zip Code: 04543-907
Building life cycle phase	Design and operation
Building typology	Commercial and Services
Digital Technologies used	Building Energy Modeling (BEM) Building Management System (BMS)
Reduction in energy consumption (%)	49.9%
Built area (m²)	257,799 m²
Participation institutions	Participações Morro Vermelho S/A Pelli Clarke Architectural Firm Pelli Architects CBRE

Picture 3.4 – Photograph of São Paulo Corporate Towers.
Source: Disclosure/Union RHAC.

Energy efficiency initiatives

The initiatives listed below are designed for building, with the aim of reducing energy consumption and obtaining the LEED Building Design and Construction Certification:

- Determination of energy efficiency measures through thermoenergetic simulation (BEM) in the design phase;
- Implementation of a building management system (BMS) in the operation phase;
- High-efficiency internal lighting system;
- Glazing with high thermal performance and low solar factor;
- Centralized air conditioning system consisting of chilled water plant and chillers with high performance at partial loads;
- Generator sets and cooling system acting in a cogeneration arrangement, where part of the heat waste from the power generating sets is reused in the absorption chillers.

Description of digital solutions

Building Energy Modeling (BEM) was used in the development phase of the project primarily in simulations considering aspects related to façade glazing, internal lighting systems, air conditioning systems and energy/cogeneration systems, thus generating indicative of the best possible configurations to obtain higher levels of energy efficiency. The software used to perform the simulations was Energy Plus.

The BMS was used in the operation phase of the building, acting on the entire intelligent building management system, in addition to including access control interconnected to the call of elevators and individual electricity and water charging system. For the air conditioning system, in addition to the system operating in a cogeneration arrangement with the power generating sets, variable air distribution was used, providing for the division by thermal zones (façades and interior), and with air quality control sensors in the return region of the same.

Energy savings data

São Paulo Corporate Towers was the first Brazilian venture to obtain LEED Platinum 3.0 Core and Shell pre-certification. The result accepted by the U.S. Green Building Council was 49.9% annual energy cost reduction compared to the ASHRAE 90.1-2007 reference model (baseline). It was the highest score (21 points) for the LEED “Energy Efficiency Optimization” credit in Brazil for the LEED BD+C Core and Shell typology. It is important to note that this project was certified with the use of the LEED BD+C Core and Shell V3 Methodology (2009).

3.5 Case study 4 – Gávea Planetarium

The Gávea Planetarium has Public/Educational use and, because it is an existing building, the participation of digital technologies took place through an energy efficiency renovation [96-99].

Architectural features of the project

The Gávea Planetarium building is a building belonging to the Planetarium Foundation, an institution with the mission of disseminating Astronomy and Science. The construction consists of two interconnected buildings:

- The Planetarium Building, built in 1970, with a ground floor and 1,150 m²;
- The Universe Museum Building, built in 1998, with four floors (one basement) and 8,900 m².

Table 3.5 – Case study 4 – Gávea Planetarium.
Source: Made by the authors.

Title: Light SESA Agreement – Planetarium Foundation	Main use: Exhibit
Municipality: Rio de Janeiro – RJ	**Bioclimatic Zone: ZB 8**
Neighborhood: Vila Gávea	**Zip Code: 22451-070**
Building life cycle phase	Renovation and operation
Building typology	Public/Educational
Digital Technologies used	Building Energy Modeling (BEM) Computational Fluid Dynamics (CFD) Model Daylighting simulation Sensors and actuators
Reduction in energy consumption (%)	Between 1.84% and 63.02%, depending on the equipment evaluated.
Built area (m²)	10,051 m²
Participation institutions	Rio de Janeiro City Hall Light Electricity Services GIZ – German Technical Cooperation Agency Universidade Federal de Santa Catarina/Solar Energy Strategic Research Group

Picture 3.5 – Photograph of Gávea Planetarium.
Source: Disclosure/Diário do Rio.

Energy efficiency initiatives

The energy efficiency initiatives adopted (partially implemented) described below were developed within the scope of an Agreement Instrument with Light Serviços de Eletricidade S.A. and in accordance with the Strategic Plan 2013-2022 of the Planetary Foundation. These initiatives formed the basis for obtaining the Partial Labeling of BLP Building Project, Class A for Envelope and Class A for Lighting.

Envelope

- Replacement of the glazed roof of the Dome (entrance to the Universe Museum) with glass-glass photovoltaic modules with better solar factor and lower transparency, integrated with the building architecture (BIPV – Building Integrated Photovoltaics) – not executed;
- Reduction of the solar absorbency of the roof with the painting of the terraces in light colors;
- Maintenance of natural coverage aiming at reduced thermal transmittance to minimize heat input to indoor environments;

Lighting system

- Reduction of the installed power in the lighting system with the replacement of all existing lamps with LED lighting;
- Better use of natural light indoors (offices, bathrooms and others) by installing photoelectric sensors in the luminaires near the windows;
- Installation of switches in environments where there were no manual control devices for the independent activation of the lighting;

- Installation of presence sensors in the indoor parking (underground environment with an area greater than 250 m²);
- Replacement of the outdoor luminaires with an LED system, part of which is driven by integrated photovoltaic generation.

Air conditioning system

- Refurbishment of the Chilled Water System (CWS);
- Modernization and automation of fan coils;
- Implementation of a Supervisory System for the Air Conditioning System.

Description of digital solutions

The energy modeling of the building was used in the development phase of the Planetarium renovation project to assess the energy performance of the building envelope with a view to meeting the Classification A (most efficient) on the BLP Edifica Label for the implementation of efficiency measures planned energy. The software used in the thermoenergetic simulation was Energy Plus.

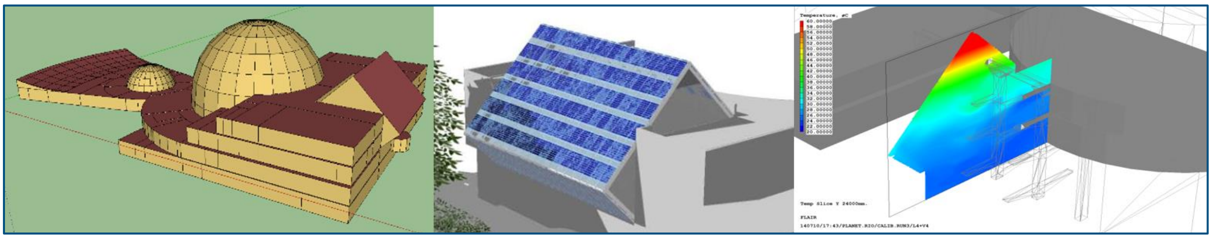
Fluid dynamics modeling (CFD) of the building was used to assess the thermal comfort of the entrance to the Universe Museum in order to predict the impact of future glass-glass photovoltaic modules integrated into the architecture and in the search for the reduction of heating from the roof. Since the photovoltaic surface is less reflective than the glass surface, the selection of the photovoltaic system took into account mechanisms to prevent (or reduce) the penetration of heat into the studied environment.

Due to the future installation of the photovoltaic modules, a computer simulation of natural lighting through the Ecotect software. The main objective was to analyze the difference in illuminance resulting from the replacement of the glass roof of the Dome and seek to obtain a better distribution of light incidence inside. The natural lighting analysis was performed at 54 points distributed over three floors and on the existing access ramp.

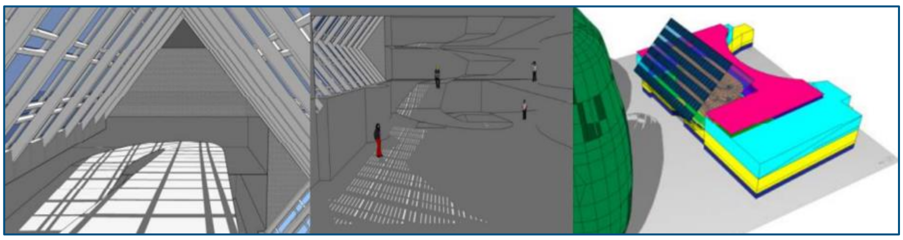
The installed sensors are responsible for measuring the quantities that you want to manage, control, or simply know. In this case, they are used by the Planetarium's air conditioning system. Actuators, within a pre-established control logic, transform generally electrical energy into mechanical energy to perform the desired function of the automation.

Energy savings data

- Envelope: the difference in final energy consumption projected by the adoption of energy efficiency measures in the envelope, comparing the Real Model and the Reference Model, is 2.66 kWh/conditioned area, which is equivalent to: 16,030 kWh/year or a reduction of 1.84%.
- PV system: it was estimated that the photovoltaic microgeneration (of the glass-glass type) to be installed on the roof of the Dome should generate from: 37,815 kWh/year, equivalent to about 3% of the building's total electricity consumption.
- Lighting: 37,309 W reduction in installed power, equivalent to a reduction of 63.02%.
- Air conditioning: Measurement and Verification (M&V) of the performance of the new installed air conditioning indicated electrical energy savings of: 896 MWh/year or a reduction of 42.55%.



Picture 3.6 – Geometric models of the proposed design and image of CFD simulation of the Gávea Planetarium.
Source: [98].



Picture 3.7 – Images of the natural lighting simulation of the Gávea Planetarium.
Source: [99].

3.6 Final considerations

The initiatives to employ digital solutions presented for the AQWA Corporate and São Paulo Corporate Towers cases are in fact relevant to the context discussed here, but it should be noted that they are exceptional examples in the national scenario, simply observing their surroundings to verify that their peers do not follow similar patterns.

Similarly, the digital solutions presented in the case of the Gávea Planetarium undoubtedly brought benefits to the building, since the pre-renovation operation situation was known, and therefore a reference value was available. There are cases, however, in which it is more difficult to segregate the efficiency values derived from improvement measures (mainly digitalization), due to their implementation since the origin of the building. This difficulty is accentuated when, after the start of the operation of these buildings, the gain in energy efficiency is not computed in a segregated way for each digital solution implemented.

The digital solution employment initiative presented for the My Most Sustainable House case is particularly interesting, insofar as it has a low cost for the project as a whole, given the diluted cost for the various housing units contemplated. The thermoenergetic simulation during the design phase provided design changes to offer considerable increase in thermal comfort and some reduction in the expected operating cost. It can be seen that there is potential for gains in energy efficiency, with low cost, when considering the use of simulations in the design phase, especially in buildings with a large number of housing units. For single-family residential buildings, there were no cases with sufficient records for an adequate report to the present study.

After research and analysis of national cases of adoption of digital solutions in buildings, it is confirmed that even though there are important examples, their adoption is still incipient in view of the number of projects that appear in the national territory. Additionally, the difficulty of setting up a case study is perceived, as the associated information is not adequately computed to be disseminated.

Appendix 3 contains the professionals and institutions that collaborated in the provision of data and information, as well as in the clarification of the case studies.

4. Recommendations

Seeking to involve as many specialists, managers, and public policy makers as possible in the propositional phase of the study, the formulation of recommendations was planned at two levels:

Technical team:
Analysis of reference documents [1; 48; 49; 57; 100-102] and conducting semi-structured interviews conducted with specialists (Appendix 1), aiming to identify relevant propositions for digitalization in the building and energy efficiency sector in the coming decades.

Representatives and guests of WG-Edificações:
Validation of the recommendations formulated by the technical team and proposal of new recommendations during the Workshop "Digitalization and energy efficiency in buildings in Brazil: analysis of barriers and recommendations", held on November 09, 2021. Appendix 2 summarizes the proposal of this Workshop, including the list of participants and the formation of the working groups organized around the four categories of barriers to digitalization in the building sector.

That said, a set of recommendations associated with the barriers analyzed in Chapter 2 is proposed in Tables 4.1 to 4.4, as a result of the participatory process foreseen for the proposal phase of this study.

Table 4.1 – Recommendations associated with institutional barriers IB1 to IB4. Source: Made by the authors.

Recommendation	Barrier
RIB1 – Revise the institutional framework for energy efficiency: • Establish governance that ensures coordination between various sectoral policies (housing, transportation, CT&I, education, environment, health, industry, energy, etc.); • Establish and publish long-term agenda for the application of program resources such as PROCEL and PEE/ANEEL but not restricted to them in a context of greater institutional coordination and integration of energy efficiency initiatives; • Reinforce the role of the MME and MDR in the sectoral coordination of policies aimed at promoting energy efficiency in the building sector.	**IB1**
RIB2 – Develop a joint plan with the participation of government agencies, public and private institutions and the third sector to promote digitalization in the building sector, with a view to exploring synergies and integrating policy instruments under the control of different bodies.	**IB1**
RIB3 – Create public-private funds to support innovation, in the form of non-refundable funds for crowdfunding, matchfunding, equity funds, among others.	**IB2**
RIB4 – Develop programs/services in niches with greater space for national technological development, focusing on digital solutions for energy efficiency in buildings (mission-oriented).	**IB2**
RIB5 – Direct the efforts of S&T institutions and companies to the development of digital solutions applicable to buildings, adopting the model of technological platforms, among other possibilities, under the coordination of the MCTI and support of the MME, MDR and ME.	**IB2**
RIB6 – Strengthen technical cooperation MDR - ABNT, with the scope extended to other competent government sectors, class entities and S&T institutions, to accelerate the process of creating, updating and publishing Brazilian standards.	**IB3**

Table 4.1 – Recommendations associated with institutional barriers IB1 to IB4. (Continued)

Recommendation	Barrier
RIB7 – Create instruments to encourage Brazil's participation in international digitalization standardization forums.	**IB3**
RIB8 – Develop and disseminate success stories of increasing productivity and energy efficiency with the use of digital solutions in buildings, by type and phase of the life cycle.	**IB4**
RIB9 – Create international technological and commercial exchange programs, mainly with leading countries in digital solutions applicable to buildings and aimed at companies in the construction sector and the building sector.	**IB4**
RIB10 – Include the theme of digitalization as a tool for leveraging energy efficiency in the existing discussion forums of the building production sector.	**IB4**

Caption: IB1 – Implementation of the various sectoral public policies in an uncoordinated manner, without synergy between the competent bodies.

IB2 – Retraction of investments in CT&I with an impact on the digitalization of sectors of the economy.

IB3 – Standardization and regulation processes do not keep up with the pace of evolution of digital technologies.

IB4 – Some of the representatives of the building sector in Brazil resist rules and regulations and their applications.

Table 4.2 – Recommendations associated with market and financial barriers MB1 to MB7. **Source: Made by the authors.**

Recommendation	Barrier
RMB1 – Improve taxation for the civil construction sector and the building sector and create financing mechanisms under differentiated conditions for the development and adoption of applicable digital solutions.	**MB1** **MB6**
RMB2 – Create specific credit lines by associating digital technologies with efficient buildings.	**MB1** **MB6**
RMB3 – Incorporate digital solutions (mainly IoT) in the white line of home appliances, making it possible to include them in rebate programs and in the PEE ANEEL.	**MB1** **MB6**
RMB4 – Encourage voluntary DEO Certification, through programs such as specific credit lines.	**MB1** **MB4**
RMB5 – Create programs for the development of suppliers of goods and services related to digital technologies for the building sector.	**MB2**
RMB6 – Promote the insertion of smart sockets to control electricity consumption in the financing of social interest housing (HIS), through a white tariff and support for demand response.	**MB3**
RMB7 – Create and keep up to date an Integrated Energy Efficiency Information System in Brazil, for a user-friendly interface aiming at interaction with stakeholders and back office with discretized databases (including data from the building sector segregated by type and phase of life cycle).	**MB4**
RMB8 – Make mandatory the labeling of new constructions and renovations of commercial, residential and public buildings in a scheduled, planned and transparent manner, with minimum levels specified by typology and by phase of the life cycle, aiming at the mandatory of all new buildings and renovations, in the market formal, in obtaining the "A" level of the PBE Edifica after 2035.	**MB4**
RMB9 – Update benchmarks for the most representative building typologies in the market, in quantitative terms and intensity of energy use, preferably through a single interface for dissemination.	**MB4**
RMB10 – Regulate Energy Performance Certification of Buildings in Operation (DEO) and automatic recertifications, based on data from smart meters and based on remote models for auditing and opening energy information.	**MB4**
RMB11 – Make mandatory the DEO certification by typology in a scheduled, planned and transparent manner, with specified minimum levels.	**MB4**
RMB12 – Encourage, through regulatory incentives (or specific credit lines), the adoption of cutting-edge technological and digital solutions in building renovations to take advantage of opportunity costs.	**MB5**
RMB13 – Promote the creation by municipalities of market incentives such as the onerous granting of the right to build for the implementation of digital solutions for energy efficiency in buildings.	**MB2**
RMB14 – Create specific R&D+I projects related to the digitalization of buildings, with a view to energy efficiency.	**MB2** **MB4**
RMB15 – Establish specific standardization for measuring and evaluating the performance of equipment integrated into buildings, as well as roles and responsibilities regarding its use and warranty.	**MB7**
RMB16 – Foster the insurance and reinsurance market related to the digitalization of buildings.	**MB7**

Caption: MB1 – Lack of specific credit lines for the implementation of digital solutions in buildings.

MB2 – Initial high costs of adopting technological solutions in buildings by a pioneer.

MB3 – Low purchasing power of users of some types for the adoption of digital solutions.

MB4 – Low availability of information on the potential and costs of energy efficiency opportunities.

MB5 – Opportunity costs (renovation need) is not used, for instance, with a focus on the energy efficiency and digitalization.

MB6 – Opportunity costs (need for reforms) not used for reforms focusing on energy efficiency and digitalization. BM6 – Impact of the costs of implementing digitalization in Social Interest Housing (HIS).

MB7 – Lack of precise definition of roles and responsibilities regarding the use and warranty of equipment incorporated into the building.

Table 4.3 – Recommendations associated with technical barriers TB1 to TB5. Source: Made by the authors.

Recommendation	Barrier
RTB1 – Adopt an international approach related to technical regulation to minimize any negative effects related to the lack of interoperability between digital solutions.	**TB1**
RTB2 – Promote the development of human-centered digital solutions applicable to buildings.	**TB1**
RTB3 – Enable investments in telecommunication (internet) infrastructure, mainly focused on broadband and mobile network, with a view to expanding adequate access to digitalization.	**TB2**
RTB4 – Strengthen mechanisms and programs for the standardization of materials and services in civil construction.	**TB3**
RTB5 – Propose standardization regarding appliances and other equipment with embedded intelligence.	**TB3**
RTB6 – Propose standardization related to the Internet of Things (IoT) in its applications in buildings.	**TB3**
RTB7 – Adopt cybersecurity standards to minimize the number of cyber attacks, as well as adequate legislation to prevent and respond to incidents.	**TB4**
RTB8 – Promote funding in S&T institutions for the development of the Internet of Things (IoT).	**TB3**
RTB9 – Promote the development of fully Wi-Fi devices to be connected to non-intelligent electronic/electrical equipment from the factory, avoiding infrastructure works and the need to exchange (before the end of its useful life) for intelligent equipment.	**TB5**

Caption: TB1 – Non-friendly interfaces hindering the adoption of digital solutions.
TB2 – Lack of internet infrastructure to provide wide and quality access for the promotion of digitalization in buildings.
TB3 – Embryonic stage in the country of standardization of processes, materials and equipment in the building sector.
TB4 – Cyber insecurity.
TB5 – Adoption of digitalization in existing homes and small businesses/services, as it requires civil works, may make its implementation unfeasible.

Table 4.4 – Recommendations associated with behavioral and skilled labor qualification barriers BB1 to BB7.
Source: Made by the authors.

Recommendation	Barrier
RBB1 – Establish a specific integrated communication plan for each public interested in building digitalization and energy efficiency in the country, emphasizing: • Not only financial but also climatic benefits (reduction of GHG emissions); • Possibility of empowering the management of energy consumption by the user; • Mapping digital technologies for each target audience; • Awareness for protection against greenwashing practices in the building sector.	**BB1** **BB2** **BB3** **BB7**
RBB2 – Create or reformulate curricula in vocational and higher education courses in relation to the topics of digitalization and energy efficiency.	**BB4** **BB5**
RBB3 – Develop a continuous training plan for professionals providing services associated with digitalization in buildings, emphasizing the clear delimitation of the scope of training, so as not to be too broad. An example would be a course focusing on each of the domains covered in this study.	**BB5**
RBB4 – Encourage technological skills programs in companies operating in the building sector.	**BB5**
RBB5 – Implement measures that allow a transition time to adapt the market to digitalization in the building sector.	**BB6**
RBB6 – Implement measures to curb greenwashing practices in the building sector, including: • Complaints to consumer protection agencies; • Exhibition/disclosure of greenwashing cases in buildings; • Homogenization of ESG parameters for companies in the building sector to build a robust and reliable evaluation framework.	**BB7**

Caption: BB1 – Resistance of the construction sector to new digital technologies in buildings.
BB2 – Low user confidence regarding the benefits of adopting digital solutions and cybersecurity.
BB3 – Culture of energy efficiency in Brazilian society.
BB4 – Outdated curricula in vocational courses and higher education in relation to the topics of digitalization and energy efficiency.
BB5 – Low supply of professional education and training in building digitalization.
BB6 – Rapid technological changes make it difficult for the market to keep up to date.
BB7 – Greenwashing of buildings.

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Appendix 1 – Semi-structured interviews conducted with specialists

The methodology for establishing the conditions of the future, barriers to digitalization, strategic implications and recommendations for digitalization in the building and energy efficiency sector in the coming decades was based on the analysis of the current situation base year 2021 of the areas associated with the object of the study, in carrying out dynamics using the expertise of team members and semi-structured interviews.

The barriers and recommendations also enjoyed the valuable participation of the WG-Buildings as described in Appendix 2.

This process resulted in the identification of 22 constraints of the future, eleven political-regulatory and eleven non-regulatory and four groups of barriers and their respective recommendations.

The following experts collaborated strongly on this study and we would like to thank them for their time, availability, experience, and vision for the future:

- Full Professor Roberto Lamberts – UFSC;
- Dr. Alexandra Albuquerque Maciel – Analyst at MME;
- Dr. Sergio Leusin – Managing Partner of GDP – Project Management and Development;
- Prof. Sérgio Scheer – Vice-President of BIM Fórum Brasil;
- Prof. Dr. Aurea Vendramin – CEO of Aurea Vendramin Consultoria e Engenharia.

The semi-structured interviews were conducted based on the following script:

QUESTION 1: Among the public policies and initiatives in Brazil aimed at digital transformation in the most diverse sectors of the economy, is it possible to identify those that are directed or that affect the residential, commercial or public building sector? If so, which ones? In particular, are there mechanisms under way or under development for the digitalization of social housing?

QUESTION 2: Two of the global goals of the 2030 Agenda defined for the seventh Sustainable Development Goal (SDG 7) relate to energy efficiency, namely: “By 2030, increase the rate of improvement of the energy efficiency of the Brazilian economy”; and “By 2030, expand infrastructure and improve technology for the provision of modern and sustainable energy services for all”. In this context, what public policies, instruments and initiatives have been implemented in Brazil aimed at energy efficiency in buildings? And to what extent can digitalization be a key driver to increase the effectiveness of these policies, instruments, and initiatives?

QUESTION 3: In the future, what will be the role of digitalization in the building sector, in the expectation of achieving higher levels of energy conservation?

QUESTION 4: One of the issues in this study refers to the intelligence adopted today in the operation of buildings in Brazil and other countries. The definition of the UK-based European Intelligent Building Group is adopted here: “Smart building consists of a multidisciplinary effort to integrate and optimize intelligent structures, materials, systems and services in order to create a productive, economical and environmentally approved environment for its occupants.” Based on this definition, what intelligent structures, materials, systems and services (e.g. Building Automation Systems – BAS; Building Management Systems – BMS) are already adopted today in the operation of buildings in Brazil? What about in other countries? Are there differences between the reality of intelligence adopted today in the operation of buildings in Brazil, compared to that of other countries?

QUESTION 5: What are the digital technologies that can be used to facilitate remote audit/inspection, aiming at building certification? Do you consider that the adoption of Standard NBR 19011: Can Remote Audit of the Management System boost the use of these technologies?

QUESTION 6: Regarding the technologies applied to the management of building demand and the surroundings, what could be highlighted in this study in terms of district management, smart district, building demand management and buildings as producers and accumulators of energy (smart grid)?

QUESTION 7: Who are the main actors, stakeholders, and influencers of the scenarios of sustained penetration of intelligent buildings in Brazil in the 2050 horizon?

QUESTION 8: What are the conditions for the scenarios of sustained penetration of intelligent buildings in Brazil in the considered horizon? In other words, what are the driving forces (e.g. incentive policy for the adoption of digital technologies); important trends (e.g. continuity of building certifications); and future-bearing facts (e.g., new generations of BIMs)?

QUESTION 9: For the construction of the most probable scenarios of sustained penetration of intelligent buildings in Brazil (2050), the following guiding question was defined to be answered in the prospective phase of the study: "What digital technologies will promote the greatest potential for energy conservation in the building sector in different digitalization scenarios, namely, fast, moderate and slow?".

QUESTION 10: What are the main barriers to the sustained penetration of smart buildings (e.g. data security; digital inclusion; need for investment, etc.) in the slow digitalization scenario? What about in the moderate digitalization scenario? And finally, in the fast digitalization scenario? It is believed that barriers can gradually be overcome, and in the slow digitalization scenario they will be more evident.

QUESTION 11: With regard to the barriers identified in the previous question, what recommendations can be forwarded to the main actors, stakeholders and influencers of the scenarios of sustained penetration of intelligent buildings in Brazil in the horizon 2050? Particularly for housing of social interest, what recommendations can be addressed to the actors involved in this issue?

Additionally, an online survey was conducted that aimed to subsidize the construction of digitalization and energy efficiency scenarios in the building sector in Brazil – horizon of 2050. This research was accessed through the link: https://forms.office.com/r/8MT0ZJwzfq.

The first page of the survey is shown in the figure below.

Appendix 2 – Workshop "Digitalization and energy efficiency in the building sector in Brazil: analysis of barriers and recommendations"

Date and time: December 09, 2021

Modality: Virtual – Zoom Platform

Duration: 1 hour and 30 minutes

Participants: Members of WG-Edificações, representatives of GIZ, MME and MDR and the Project team.

Objectives:

- Present the results of the Final Report of the Project "Digitalization and Energy Efficiency in the Building Sector in Brazil";
- Propose recommendations associated with the resolution of barriers to digitalization in the building sector in Brazil, in the horizon 2050, taking as a starting point a set of preliminary recommendations proposed by the Project team;
- Promote the exchange of ideas and sharing of the recommendations proposed in this Workshop.

Preliminary activities

- Reading of the Executive Summary of the Final Report sent to the participants;
- Analysis of the recommendations, directed to one of the four categories of barriers:
  - **i.** Institutional;
  - **ii.** Marketing and financial;
  - **iii.** Techniques;
  - **iv.** Behavioral and qualification of specialized labor.

Note: For the second previous activity, the WG-Edificações Coordination will indicate the formation of groups around the four categories of barriers.

Program

Activity	Responsible person	Duration	Description
Overture	MME/GIZ/GT-Edif.	5 min	General objectives of the workshop
Presentation of the Final Report	Growing Energy	20 min	Summary of results
Debate and general guidelines on the conduct of the activity in groups	Growing Energy	5 min	Clarifications regarding the presented content
Formation of the groups	Growing Energy	5 min	Organization of groups in virtual rooms
Group activity	Groups supported by Growing Energy	20 min	Analysis, discussion and completion of the template for presentation (ppt)
Presentation of the groups and plenary discussion	Representatives from each group	30 min (7 min per group)	Group presentations: Recommendations by barrier category to the digitalization
Closing of the Workshop	MME/GIZ	5 min	

Participants

Participant	Institution
Alessandra da Costa Barbosa	Cepel
Alexandra Albuquerque Maciel	MME
Ana Cristina Braga Maia	EPE
Andiara Campanholi	MDR
Anna Carolina Peres	Growing Energy
Elisete Alvarenga da Cunha	Eletrobras
Estefania Neiva de Mello	Eletrobras
George Alves Soares	Growing Energy
João Queiroz Krause	Growing Energy
José Sergio dos Passos Oliveira	MDR
Kristina Kramer	GIZ
Marcos Alexandre Izidoro da Fonseca	Growing Energy
Maria Fatima Ludovico da Gama e Souza	Growing Energy
Mariana Martins	CBIC
Myrthes Marcele Farias dos Santos	Growing Energy
Natalia Gonçalves de Moraes	EPE
Rodrigo Flora Calili	Growing Energy
Stéphanie Gomes	GIZ
Telesmagno Neves Teles	ME

Composition of the groups

Group	Participants
IB – Institutional barriers	Alexandra Albuquerque Maciel (MME) José Sergio dos Passos Oliveira (MDR) Telesmagno Teles (ME) George Alves Soares (Growing)
MB – Market and financial barriers	Ana Cristina Braga Maia (EPE) Mariana Martins (CBIC) João Krause (Growing)
TB – Technical barriers	Alessandra Barbosa (Cepel) Elisete Alvarenga da Cunha (ELB) Myrthes Marcelle (Growing) Marcos Fonseca (Growing)
BB – Behavioral and skilled labor qualification barriers	Estefania Mello (ELB) Natalia Gonçalves de Moraes (EPE) Andiara Campanholi (MDR) Anna Peres (Growing)

Appendix 3 – Professionals and institutions providing case study information

We express our thanks to the institutions and professionals who dedicated their time and availability to provide and clarify information about the case studies. The list is stratified by case study.

Case study 1 – Minha Casa Mais Sustentável

People interviewed

- Marina Amorim Cavalcanti de Oliveira – National Housing Secretariat – SNH/Ministry of Regional Development
- Elisete Cunha – Eletrobras/Procel Edifica
- Maria Lucia Percly – FAU/UFRJ Housing Network
- Joyce Carlo – Universidade Federal de Viçosa

Institutions involved in the building design

- National Housing Secretariat – SNH / MDR
- Eletrobras/Procel Edifica
- Prourb – Urban Planning Graduate Program at UFRJ
- FAU/UFRJ Housing Network
- Energy Efficiency Network (R3E) / UFV

Case study 2 – AQWA Corporate

Interviewee

- Eduardo Yamada – Building Technology Center – CTE

Institutions involved in the building design

- Foster Architecture Firm + Partners
- Tishman Speyer Properties

Case study 3 – São Paulo Corporate Towers

Interviewee

- Eduardo Yamada – Building Technology Center – CTE

Institutions involved in the building design

- Participações Morro Vermelho S/A
- Pelli Clarke Architectural Firm Pelli Architects
- CBRE

Case study 4 – Gávea Planetarium

Institutions involved in the building design

- Rio de Janeiro City Hall
- Light Electricity Services
- GIZ – German Technical Cooperation Agency
- Universidade Federal de Santa Catarina / Solar Energy Strategic Research Group

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