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Sustainable Built Environments: Building Information Modeling, Biomaterials, and Regenerative Practices in Mexico

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Abstract: This article explores how the construction sector can significantly contribute to minimizing its environmental impact through reuse and recycling practices, in rehabilitation or new construction projects. This research focuses on implementing BIM methodology alongside biomaterials, 3D modeling, and digitization in compliance with the Green Building Code. Two case studies located in Jalisco and Querétaro (Mexico) are examined through a comparative analysis. The simulations are carried out in different geographical areas with two construction systems that allow us to see the output similarities. The results show the clear advantages of biomaterials over traditional materials such as concrete. The construction materials are shown to determine their operational energy consumption. From an economic point of view, this study supports data regarding lower energy costs, and a significant reduction in CO_2 emissions is observed. In conclusion, both the models and simulations, along with the Toolkit, highlight the benefits of biomaterials over conventional industrial materials.

Keywords: BIM; multi-scale analysis of society and ecosystem metabolism (MuSIASEM); circular urbanism; green building; materials catalog

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1. Introduction

Following the World Development Alliance held during the Millennium Summit and the subsequent approval of the Millennium Development Goals (MDG) [1] in 2000 and later in 2015, a comprehensive active plan emerged. The focus was on the people, the planet, and its prosperity in alignment with sustainable development objectives (SDGs) [2]. This initiative aimed to raise awareness among the public regarding the complexity of the challenges we face, emphasizing the need for change and responsibility at all levels. The collaborative efforts span from the individual to the collective in the local, regional, national, and global spheres [3].

Consequently, the ODS 11 was defined as the manifestation of the urban dimension, making cities more inclusive, safe, resilient, and sustainable [4]. The global recognition of urbanization as a catalyst of development and social transformation has shaped a new international landscape. This is characterized by the adoption of important agreements, such as the 2030 Agenda for Sustainable Development, the Addis Ababa Action Agenda on Financing for Development, and the Paris Agreement on Climate Change. These agreements and the New Urban Agenda (NUA) underline urbanization as a transformative force which is vital in solving prevalent global issues, declaring a need for global commitment [5,6].

This global approach lays the foundation for the "Ecological Conceptualization of Cities," where urban centers are seen as living organisms that grow, develop, and, at some point, may die. Originating from the seminal work on urban metabolism, this perception attempts to understand and respond to the causes of deteriorating water and air quality in North American urban centers. Represented by a block diagram and supported by equilibrium equations, this model links material flows into the city with the amount of waste it generates. Figure 1 presents a visual mapping of cities that have conducted urban metabolism studies [7].

Figure 1. Cities that have urban metabolisms in the world today. Note: Cities in which urban metabolism studies have been carried out for (a) an analysis of sustainability, growth, availability of resources, habitability, and vulnerability; (b) a solution for environmental problems including the reuse and recycling of materials and water; and (c) the identification of critical processes and the reconstruction of cities.

This article focuses on urban decarbonization from different theoretical perspectives. Although the leading causes linked to CO_2 emissions produced by cities have been conceptualized, defined, and identified, we have identified an essential preliminary step: the response of technological solutions. This aspect involves using various simulation and design process management software programs, which are considered relevant tools for decision-making based on earlier analyses under current conditions. The objective is to improve conditions in terms of mitigation or in the design of projects yet to be built to anticipate the behavior of the building in the context of preventive measures.

Our research aims to explore the applicability and effectiveness of these technological tools in planning and sustainable urban design. The goal is to contribute significantly to the reduction of carbon emissions, thus confronting climate change. By filling this research gap, we aim to clarify how these technologies can improve sustainability in urbanization and urban project development.

1.1. Towards a Comprehensive Understanding of Urban Sustainability: Approaches and Strategies

From a physicochemical perspective, the city is interpreted as a system that consumes various materials, transforming them into unnatural products and by-products in unprecedented quantities and varieties [8,9]. This view evolved to consider the flows of matter and energy as connections between the economic system and the surrounding environment [10], giving rise to the analogy of the city as a superorganism that intertwines ecology with the mixed economy [11,12]. According to [13], this "system" involves a series of processes by which human beings, in their social organization and over time, acquire, recycle, transform, consume, and excrete matter and energy from the natural world. This approach highlights the city as a complex reality—a sum of its parts and the elements that compose it. It maintains common elements such as processes, flows of matter and energy, and society [14,15].

In the specific context of Mexico, analyzed through two case studies, it is observed how urban metabolism converts the natural elements of urban centers into social and economic values [16–20]. These studies focus on the National Development Plan 2019–2024, which seeks to build a country with well-being, prioritizing the most vulnerable social classes through social justice and considering national priority problems [16]. Throughout the last 60 years, different stages in Mexico's housing policy have been identified, highlighting the transition from an interventionist model to financial support with significant effects on urban growth management. In addition, the importance of understanding the complex systems that make up cities and the problems related to their development is highlighted, emphasizing the pressures that urban natural resources need and that waste disposal exerts on natural systems [21,22]. This understanding is crucial to address urban decarbonization and to explore innovative technological solutions, such as simulation and design management software, in order to improve urban sustainability and mitigate CO_2 emissions [22].

1.2. Urban Metabolism

Urban metabolism, a concept introduced by Wolman [8], encapsulates the myriad of technical and biogeochemical flows within cities, drawing a parallel with the metabolic processes of living organisms. This framework sheds light on the urban consumption of resources like energy, water, and materials alongside the production of waste and emissions, positing a novel lens through which to view and manage the environmental challenges of urban living.

Regarded as an invaluable asset by academia and government sectors, urban metabolism offers a multifaceted approach to comprehending urban dynamics and advocating for their sustained existence amidst changing climates. The concept has proven particularly pertinent in the post-pandemic landscape of Latin America and the Caribbean region, where it has highlighted the entrenched development issues magnified by rising unemployment—disproportionately impacting women—and inflationary trends that erode the populace's income [23].

In Mexico, the quest for sustainable housing that aligns with the ecological landscape which fosters social equity and socioeconomic upliftment is challenged by systemic inequities and a scarcity of resources. Addressing such multifaceted issues demands a diverse public response that acknowledges the intricacies of these societal differences.

The New Urbanism movement aspires to cultivate cities founded on principles of diversity, identity, and sustainability. In Mexico City, the escalating value of land has intensified housing issues, driving segregation and displacement due to the inability of residents to cope with the surging economic demands. Creating affordable, eco-efficient living spaces is thus essential, factoring in the critical roles of cost and location in mitigating waste generation and CO_2 emissions.

1.3. Decarbonization of Cities

Cities must lead the world's shift to a decarbonized building sector. With a high percentage of the world's population now living in urban areas, cities largely determine the future of their countries. Actors from different levels of government and the public and public–private sectors must collaborate to overcome political and market barriers and make decarbonized cities a feasible and desirable goal [14]. It is essential to propose alternatives for reusing and recycling materials and water to meet the increasing demands in various sectors of the economy [24]. In addition, consulting firms have employed this metabolism to model the demand and supply of resources in urban systems that require a reconstruction process after a catastrophic event [25] (see Figure 2). From this aspect, the activities that were carried out positively impacted the transfer of R&D knowledge to carry out work on the synthesis and formulation of new materials, analysis of the physical–chemical and resistant properties of the materials, behavior in service, prototyping, and material treatments. The particular contribution in each line treated together with their transversal research contributes to the sustainable development objectives (SDG) regarding the critical aspects of affordable and non-polluting energy, sustainable cities and communities, responsible production and consumption, and climate action, among others.

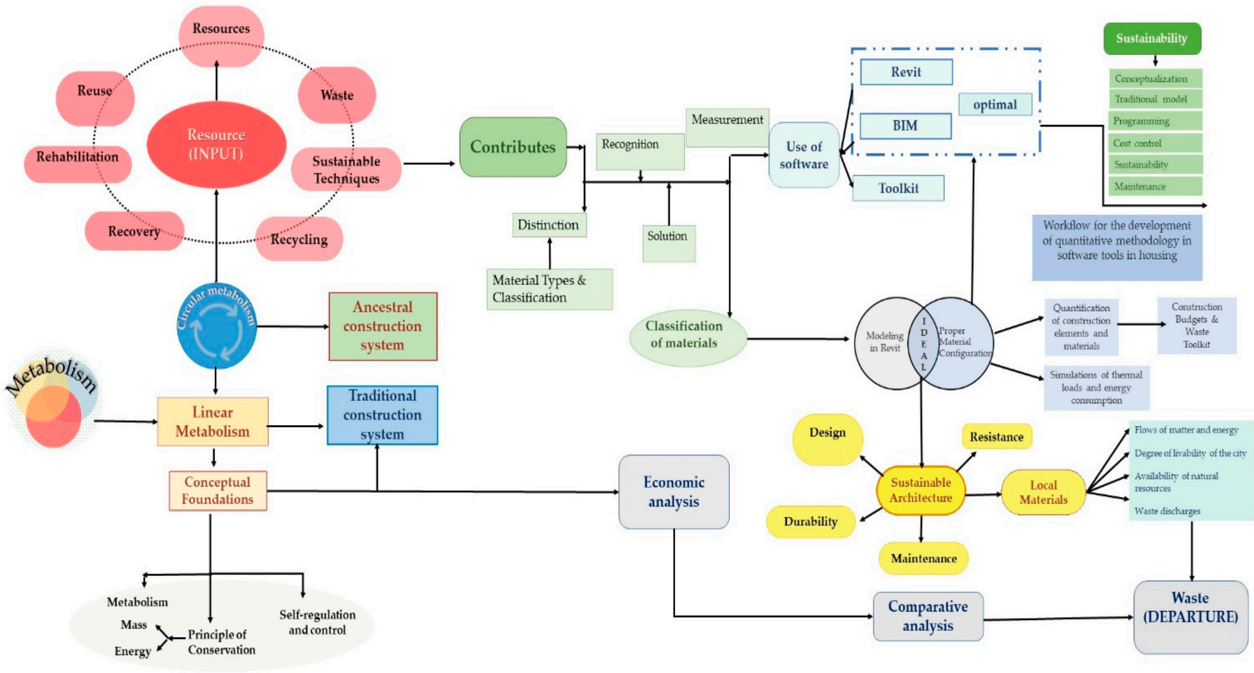


Figure 2. Mining of materials studied from the territory applied to buildings—authors' own elaboration.

Before developing a circular housing model that contributes to the environment, it was necessary to propose a strategic planning model, as shown in Figure 2. This allowed us to analyze the energy consumption and waste in relevant aspects of C&D.

When it is possible to conserve more energy and other values, such as embodied work, circular systems use tighter internal loops. By extending the useful life of products and promoting their reuse, this type of system reduces the speed of product rotation. By removing valuable biochemical components and cascading them into several increasingly more straightforward applications, circular systems maximize the use of bio-based materials at the end of their useful life.

In the National Territorial Policy (NTP), the management of these assets combines the creation of communication channels with various stakeholders and the use of laws, regulations, policies, and instruments to carry out comprehensive settlement activities, occupations defined as "Land Use in Urban Development" [26]. Its objective is to mobilize the real estate market to remedy the socially unacceptable inefficiencies caused by the economic nature of the country in the processes of speculation, occupation processes, irregular areas, urban growth, and recycling [27,28].

1.4. Models and Strategies for Sustainable Urban Development

Urban geography and circular urbanism are intertwined disciplines pivotal to sculpting sustainable urban strategies. Urban geography delves into the spatial dynamics of city development—analyzing urban growth, interactions with the rural milieu, and internal city phenomena like land use and social dynamics [29]. This discipline advocates for designing urban spaces that are attuned to their biophysical context, promoting a sustainable blueprint for urban construction and development.

Concurrently, circular urbanism, rooted in the principles of the circular economy, poses a transformative strategy for urban planning. It aims to revolutionize the building life cycle by closing the loops of material and energy flows, thus addressing the intensifying demand for construction materials while minimizing ecological footprints [14,30–33]. The construction sector, a significant contributor to global CO_2 emissions, benefits significantly from this paradigm, as circular practices can diminish resource overuse and propel cities toward a decarbonized future.

Combining urban geography's comprehensive planning framework with the actionable measures of circular urbanism provides a robust approach to urban sustainability. This dual strategy fosters the creation of cities that respect environmental limits and ensures they are equipped to face modern urban challenges, steering urban development towards resilience, livability, and sustainability.

1.5. Tool and Technology: 3D Modeling and Digitization at the Service of Sustainable Building Construction (Green Building Construction)

BIM (Building Information Modeling) is a multidimensional digital methodology that collaboratively manages the development process throughout the life cycle of a project. This method mimics the actual construction process and encompasses several dimensions, including three-dimensional modeling, time analysis, cost quantification, and sustainability, the latter focusing on environmental, economic, and social aspects [34]. The sustainability dimension of BIM, or 6D BIM, enables analysis, calculations, and simulations to improve project quality, encompassing energy simulations, the building's life cycle analysis, material recycling, and carbon footprint, resulting in fast and accurate solutions and a detailed analysis of various economic and operational aspects throughout the project's life cycle.

Life cycle analysis (LCA) assesses the environmental impacts during the lifetime of a building, considering aspects such as global warming, acidification, ozone depletion, energy consumption, and waste. BIM 6D, in the context of LCA, allows the assessment of buildings' environmental impacts from design to demolition, optimizing processes and achieving better results. In this framework, Autodesk Revit software, version 2023 with its innovative BIM technology, facilitates modeling and simulation, projecting predictive scenarios for buildings and quantifying and simulating energy and material consumption [35] (see Figure 3).

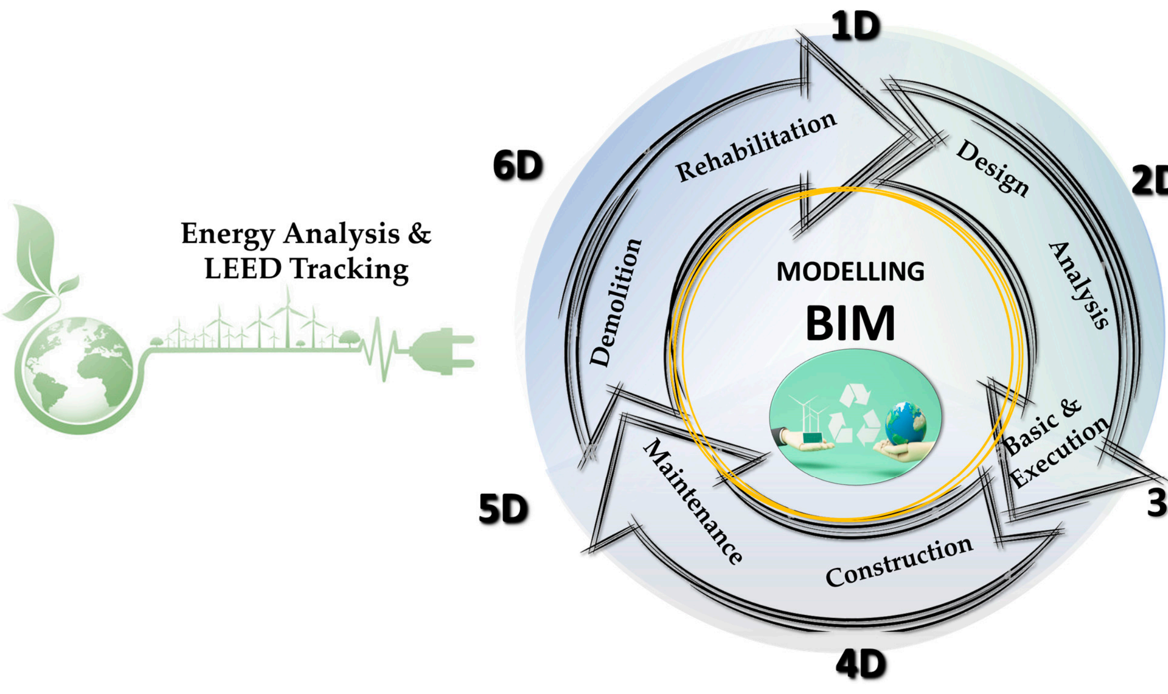


Figure 3. Buildings' life cycle and dimensions in BIM—authors' own elaboration.

In construction, energy consumption in buildings, CO_2 emissions, and the properties of materials represent significant impacts not only in the construction of houses but also in their daily use. A comparative study of two buildings in different geographical areas and with different construction systems, including the Traditional Construction System (TCS) and the Ancestral Construction System (ACS), allows us to obtain their energy consumption and efficiency. This approach enables strategic and orderly planning based on the needs of each designer, providing productive tools for modeling, simulations, and quantifications, contributing to the energy transition of the building sector towards circularity [34].

Finally, two key trends in architecture and construction are highlighted: circular housing and the circular economy in the real estate sector. Circular housing, focusing on reducing environmental impact through recycled materials, is positioned as an essential scenario for minimizing human impact on the environment. On the other hand, the circular economy in the real estate sector emerges as a philosophy of systems organization based on living beings focused on designing products without generating waste and on business models that encourage the collection, remanufacturing, and distribution of products [36–40].

This orientation not only improves the image of companies but also reduces material and energy costs, waste and emissions management, and fiscal/legislative risks, opening up new opportunities for innovative product design and business markets.

1.6. Applying MuSIASEM Methodology for Energy Analysis in Housing Construction within Informal Settlements in Mexico

In this paper, we draw upon the interconnected theories of Urban Metabolism, Decarbonization of Cities, and Models and Strategies for Sustainable Urban Development, underpinned by the technological framework provided by BIM (Building Information Modeling), to form the theoretical basis of our methodology. As conceptualized by Wolman [8], Urban Metabolism offers a holistic view of the flow of resources in cities, highlighting the need for efficient management of these flows to address environmental challenges [23,35]. This concept intertwines closely with the urgent imperative of Decarbonization of Cities, which aims to reduce carbon emissions and foster sustainable urban development [14,24–28]. Concurrently, our approach incorporates key insights from Urban Geography and Circular Urbanism [14,29–33], emphasizing the importance of spatial planning and adopting circular economy principles in urban development. These theoretical underpinnings are operationalized through BIM, a multidimensional digital methodology that supports life cycle analysis, energy simulations, and sustainable design processes [34]. BIM's capabilities to model, simulate, and quantify various aspects of urban construction make it an invaluable tool in our methodology, enabling us to address the complexities of urban sustainability and the energy transition of the building sector towards circularity.

As we bridge theoretical constructs with practical methodologies, it becomes imperative to integrate the Urban Metabolism framework with the MuSIASEM methodology, which is pivotal for realizing the vision of an innovative, sustainable city. Urban Metabolism, a mosaic of social, technological, and ecological facets, orchestrates the flow of resources that dictate urban functionality and fulfill the needs of its populace [41]. Nevertheless, the intricacies of urban metabolism in informal settlements necessitate meticulous resource management data, often hindered by informational discrepancies [41–43]. The MuSIASEM model emerges as an analytical beacon, scrutinizing ecosystem and societal dynamics through a lens that harmonizes biophysical and socioeconomic domains [44,45]. Its analytical prowess stems from an eclectic blend of scientific domains, offering a systemic view of societal energy patterns and value creation within urban settings [46]. MuSIASEM's contextual language principle enhances stakeholder communication, fostering a nuanced understanding of urban complexities [44]. This comprehensive methodology steers our case study, underpinned by social, economic, and ecological considerations, towards a multidimensional analysis that effectively informs sustainable urban development strategies.

1.7. Justification for MuSIASEM Application

Research into the energy used in housing construction within informal settlements in Mexico demands a methodology capable of addressing complex, multi-scale interactions. The MuSIASEM methodology is apt for this purpose as it allows for an integrated analysis of urban systems' biophysical and socioeconomic dimensions [42,43,46]. Informal settlements pose particular challenges for data collection and resource management due to fragmented information and the absence of formal systems [41]. MuSIASEM's versatility and ability to characterize social metabolic patterns across scales make it an invaluable framework for examining the intricate web of energy flows within these communities, from individual dwellings to the broader urban context.

The MuSIASEM "grammar", implemented in simulation software such as BIM, is an essential guide for contextual data organization and process modeling. This methodology prescribes a structuring of data that reflects the interaction between the macro context, encompassing the urban and rural environment, and the micro context, focusing on building materials and energy systems [44]. Such an approach enables the simulation of various scenarios, from resource allocation and consumption patterns to waste generation, ensuring that these reflect the socioeconomic realities and ecological imperatives of the informal settlements under study. By integrating these dimensions, the MuSIASEM methodology promotes the development of a simulation that is theoretically grounded and practically applicable to the specific conditions of these communities. According to the scheme description, we seek to visualize how the MuSIASEM methodology is applied using simulation software to decarbonize cities, focusing on the social, economic, and ecological dimensions (see Figure 4).

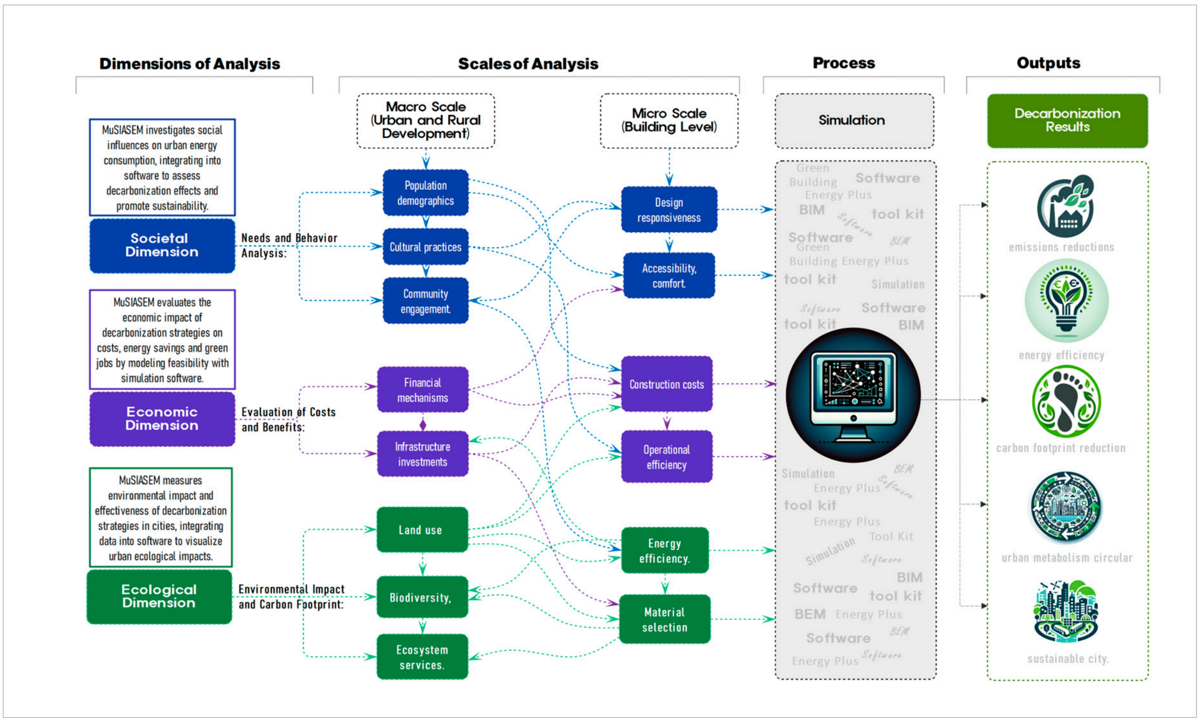


Figure 4. MuSIASEM Integrative Framework for Energy Simulation and Urban Decarbonization. Authors' own elaboration.

1.8. Study Cases: Querétaro and Guadalajara, Mexico, as Focused

Mexico is diverse, ranging from the climate to different altitudes and longitudes in its cities. Guadalajara is one of the largest metropolises in the world, and Querétaro is a desert state. Both cities contrast due to their population density, climates, temperatures, and, above all, the meters above sea level in which they are located. The first intention is to use two buildings that contrast in their location, context, and design for analysis as case studies. On the other hand, in terms of their spatial dimensions, they are similar, but their design is not. In Querétaro, there is the first case study called “Hostal el Labradío,” currently aimed at the general public to enjoy a stay, with an organic design of the building, implemented under the “Nebraska” type construction system (ACS, from now on), using biomaterials such as straw bales, wood, raw soil, and bamboo. The second case study is located in Guadalajara; it corresponds to a private single-family home currently under construction, where a “Traditional” construction system (TCS, from now on) is implemented with an orthogonal design standard in Mexico, made up of materials such as concrete, metals, annealed brick, and mortars.

Both buildings have different characteristics, so an analysis of both case studies under simulations with the mentioned construction systems is needed. Four models are developed with their respective simulations corresponding to the two buildings described, both modeled and simulated with the above construction systems (ACS and TCS). The case studies are delimited under the same parameters both in materials configured in BIM, temperatures to be simulated, and the results produced by the BEM analysis, having only as variables the locations of the projects, the data obtained by the meteorological stations (corresponding to the geographical locations), and the dimensions of the developed and simulated models. These two case studies are selected due to their context:, the first is located in a rural area, its design is organic (circular geometry), it is built with an ancestral construction system, and it uses biomaterials (Querétaro); and the second is in an urban area, its design is orthogonal (square and rectangular geometry), and its construction system is traditional in addition to using common and industrialized materials (Guadalajara). Derived from the above, our study is carried out with these two case studies, and they are each modeled with the two construction systems mentioned (ACS and TCS) to analyze and verify the benefits and advantages that the materials could provide in each construction; regardless of where the buildings are located or the type of design used, the study will only compare the variations that occur when using traditional materials versus biomaterials.

In addition, to analyze the advantages of decarbonization, costs, and energy consumption in buildings derived from the materials used in construction, it is essential to develop models and simulations both in BIM (Building Information Modeling) and BEM (Building Energy Modeling). First, BIM is made up of a methodology developed by Autodesk in the Revit software to insert the necessary information into the models, ranging from materials to construction systems for proper planning, ordering, and quantification. Second, BEM must be developed once the modeling has been carried out with BIM to obtain energy data and future consumption data generated by the modeled building, derived from its BIM configuration and from the geographic location where it is developed with the previous configuration of parameters obtained from the Autodesk server and from the weather stations closest to the building site. By carrying out modeling and simulations of this type, we obtain good planning for the building and, more importantly, sustainable urban development, not only by using resources and materials but also from the reduction in energy consumption of the building itself through the taking advantage of the benefits of its area, producing the ideal building by considering the place where it will be built and its geographical benefits, to “build without building,” through the use of biomaterials, as well as by considering the environmental properties of the location.

2. Materials and Methods

The materials and methods of this study have been meticulously selected to align with a phased structured workflow by the Mu-SIASEM methodology. The research begins with data entry into the BIM software version 2023, specifically using Revit, to represent ancestral (ACS) and traditional (TCS) building systems and integrate state-of-the-art materials. This initial phase lays the foundation for quantifying and classifying materials extracted from Revit, which feeds the configuration and simulation in EnergyPlus.

The second phase focuses on applying advanced tools such as Insight, which facilitates detailed simulations and optimization in sustainable construction aligned with the 2030 Agenda. The results of these simulations are extracted and compared for both building models.

In the final phase, the results are subjected to an exhaustive comparative analysis, culminating with the recommendation of the optimal models based on sustainability and energy efficiency criteria. These models are presented as the preferred solution for the final disposal of waste, with options for reuse, recycling, or landfill control based on the Toolkit developed by the CONDEREFF project for adequate and responsible waste management [45]. The research methodology incorporates iterative feedback to ensure that the simulation models are deeply rooted in the operational and environmental realities of the target communities [34] (see Figure 5).

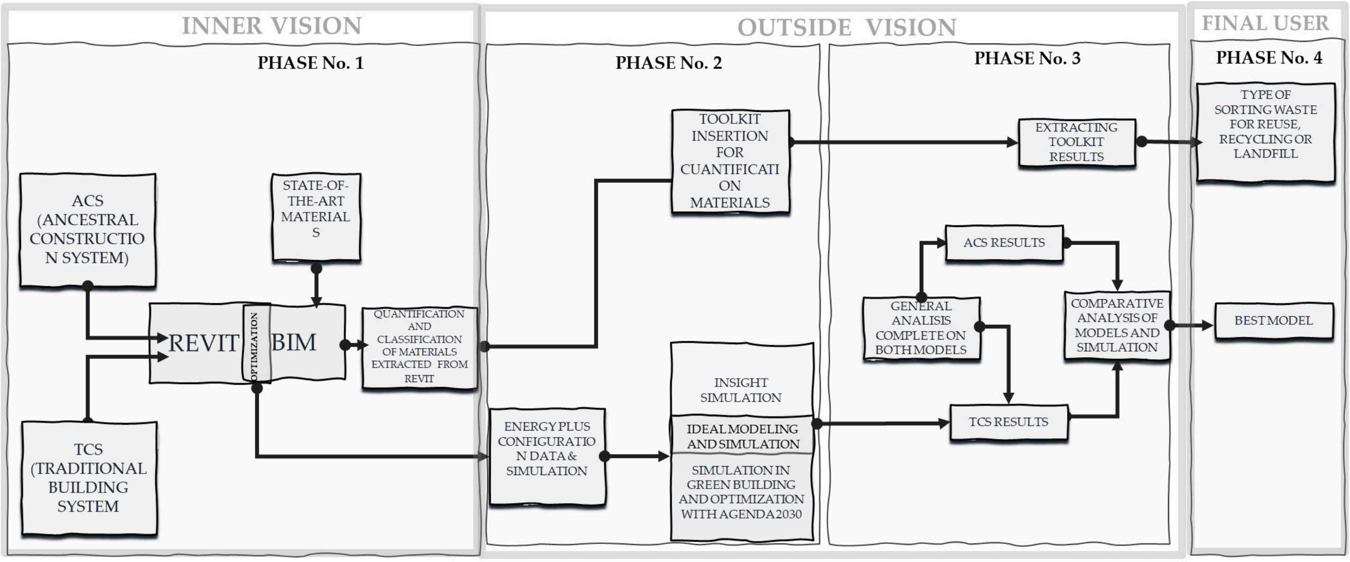


Figure 5. Methodology of four phases developed for the Guadalajara and Querétaro models for the study. Authors' own elaboration.

Also, the four phases that comprise the described methodology are developed in this section, ranging from modeling and simulations to the analysis of results. Due to the magnitude of the work, the developed process of only one model will be described. However, for the following sections, the results of both systems will be described.

The methodology derives from the previous modeling and configuration of materials (BIM) in the two scenarios to be studied, comprising four simulations, including the construction systems described for each model. Subsequently, we subject them to the following simulations.

- Energy Plus.
- Insight.
- Green Building.

Phase 1: Modeling, BIM configuration, and materials quantification for Toolkit.

In Revit Software version 2023, it is necessary to understand that it is not CAD Software version 2023 (Computer Assistant Design) but software initially based on configurations under a previously established informative order to carry out the corresponding modeling. Figure 6 shows one model developed as an example called "Querétaro".

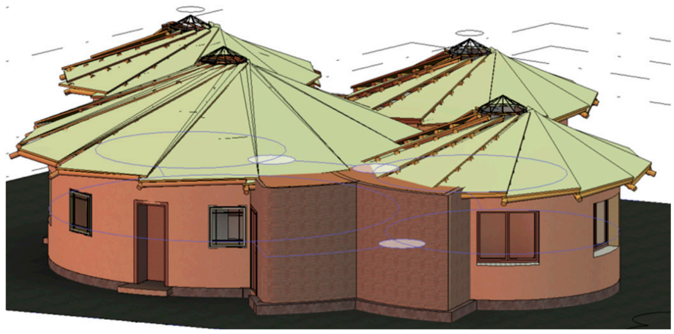


Figure 6. Model developed on Revit with BIM and BEM simulations for the study.

Initially, the BIM methodology is based on preconfigured information in the software, comprising physical and thermal properties previously assigned by the program developer (Autodesk, Revit), simplifying the assignment of materials for the TCS, covering materials such as concrete, sand, steel, brick block, etc. The BIM work methodology allows the model to acquire information and store it for later use, depending on the user's development. Revit contains materials commonly used in the construction sector; however, models composed of "Biomaterials" have been configured previously. Initially, the development of the study is based on a previous investigation of the state of the art to obtain information on material parameters that are not preconfigured in the software and to take advantage of those previously configured, starting with the editing of bamboo and straw bales because they are materials derived from the ACS. Table 1 describes the parameters configured in the software for the material called "bamboo" due to its personalized configuration as a biomaterial. However, the software has many preconfigured materials and construction systems used in BIM modeling. The versatility of the BIM tool has vast benefits, as shown by [47,48] in his study. However, in the case of biomaterials, the preconfigured information is reduced, resulting in a personalized edition for the present study. Exhibit 1 shows the materials used for the present study.

Table 1. Editable parameters for biomaterials in Revit with BIM for simulation.

Thermal Properties in BIM of Bamboo		
Description	**Quantity**	**Units**
Behavior	Isotropic	N/A
Thermal conductivity	0.54	m·k
Specific heat	0.84	J/ (G·°C)
Density	1550.00	Kg/m^3
Emissivity	0.95	N/A
Permeability	182.4	Ng/(PA·s·m^2)
Porosity	0.01	N/A
Reflexivity	0.00	N/A
Electric resistance	2,000,000.0000	Ω·m

The development of BIM modeling and configuration of materials and biomaterials comprises an essential stage for their ideal functioning, considering the variables shown in Table 1 and introducing them into the BIM configuration. To fully develop simulations, it is necessary to understand their development based on a cascade effect, where, in order to carry out a simulation, it is required to have completed the previous phase, without exception, to obtain the results closest to reality; the configured and resulting information is then subsequently used by part of the software for further processing.

Regarding the quantifications of the model with materials in Revit for the Toolkit (demolition and construction waste), the BIM methodology through the workflow in the software dramatically facilitates the work due to the Revit modeling system (modeling based on construction systems), carrying out the quantifications with the software from modeling to completing the BIM configuration of materials, thus making it possible to classify them. Also, through the planning and quantification tables tool that the software provides, the data are acquired for the Toolkit (Construction and Demolition Waste, CDWs); in this way, the quantifications depend on the model and its configuration, attributing only the task of extraction to the user. The tables of quantification extracted from the software are shown in Exhibit 2.

Phase 2: BEM configuration for Energy Plus, Insight, and Green Building.

Energy Plus

We developed the 3D model and its configurations of materials and biomaterials in BIM. The Energy Plus simulation is the first to be run according to the abovementioned methodology. The designation of zones and spaces to analyze in the simulation based on the projected design is shown in Figure 7 below.

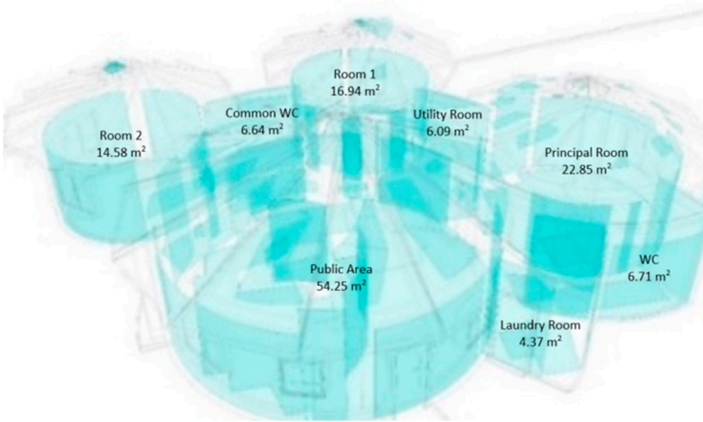


Figure 7. Assignation of zones and energetic spaces for Energy Plus analysis and simulation.

Subsequently, using the meteorological station closest to the location of the building, the parameters are obtained for use in Energy Plus, which will be essential for the software to develop the corresponding simulation and thus obtain the energy consumption relating to the energy simulation of the models. Table 2 shows the second configuration stage concerning the geographic data of the model. This process is carried out in the four scenarios proposed and executed with the four Energy Plus simulations.

Table 2. Configuration of geographic parameters according to the weather station closest to the Querétaro model with ACS in Revit.

Location and Climate	Description
Project	House
Ubication	Guadalajara
Calculation Time	Saturday, 25 February 2023, 2:41 p.m.
Report Type	Detailed
Length	20.48°
Latitude	−103.64°
Dry Summer Temperature	37 °C
Humid Summer Temperature	23 °C
Dry Winter Temperature	−4 °C
Mean Hourly Oscillation	16 °C

In addition to the configurations shown, it is necessary to establish parameters for both the areas of the model to be analyzed and the energy spaces to be simulated. The configuration is made up of different parameters to configure and consider for the simulation in Energy Plus of Revit as contemplated [47–50]; however, for the present study, it is only developed in Revit, and the SketchUp software version 2022 was not used to obtain the models and predictive quantifications of the energy models in this section. Among the configurations developed, the analytical spaces configured for the model stand out, establishing interior and exterior air flows according to the nearest meteorological station set in L/(s·m^2). Regarding the maximum and minimum cooling values, consumption is assigned in Watt (W) for a conventional ventilation and temperature conditioning system, and cooling and heating values are assigned for the ideal interior temperature (24 °C). Regarding lighting and occupancy load, the configuration is preserved so as not to potentiate variations in the results and to be able to appreciate simplified quantifications without complicating the purposes of this study.

The simulation collects preconfigured data from both energy zones and areas designated in the model and, based on the information provided by the weather station, develops the corresponding quantifications for the consumption of the building without occupants for the ACS and TCS in the Querétaro model. However, the ACS has less m2 and m3 than the TCS, which is attributable to the design of the building and the construction system. However, the energy consumption is used to condition the spaces in both cooling and heating. The measurements of the spaces in the simulations of the Querétaro model vary quite independently. Exhibit 3 shows the results of the Energy Plus simulation described for the Querétaro and Guadalajara models, both with ACS and TCS.

2.1. Insight as a Simulation Complement

As mentioned above, each simulation is executed according to the methodology, using the information produced by Energy Plus, which will be used to execute the Insight simulation. The Autodesk Green Building server is accessed to obtain the information provided by Insight. An account on the Autodesk platform is essential to access the interface and perform the predictive analysis configured by the Autodesk company. This platform collects data from both the BIM model, the information produced by Energy Plus, and the data from the weather station. The interface sends all the files and data to the server. It processes them, performing an energy analysis based on a comparative analysis of the energy consumption of buildings similar to the one sent to the server, and then subsequently notifies the users by email of the completed analysis, delivering the energy consumption of the model based on the cost in dollars per square meter. Exhibit 4 shows the interface of the Insight plugin used in the simulations described.

Insight also suggests optimizations in both window design (to improve and take advantage of sunlight and natural light) and in the use of electronic devices to take advantage of low electricity consumption in terms of schedules and the natural lighting of the building spaces. In addition to using photovoltaic panels, the program suggests the orientation and number of devices for the building's consumption as developed [51]. The above is suitable for optimizing the model and conducting comparative studies between different developments and their uses. However, for this study, only the energy consumption of the models is necessary for subsequent analysis derived from the materials used, which was also developed by [51,52].

2.2. Green Building Studio

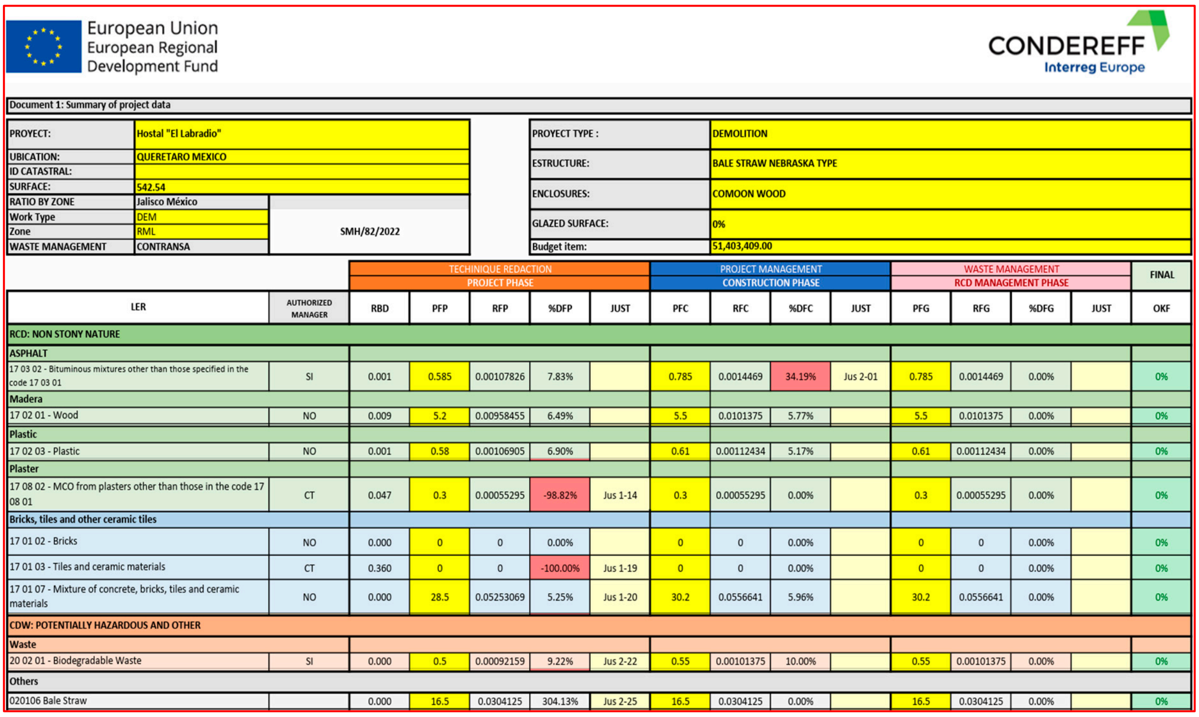
Once the Insight simulation is developed, the Green Building Studio program runs, and an analysis of the model's costs without the suggestions of Insight is obtained. Some of the parameters that can be obtained with this simulation are as follows:

- Energy cost.
- Annual carbon emissions.
- Annual intense energy consumption (fuel and energy).
- Energy life cycle (fuel and energy).
- Energy consumption of air conditioners.
- Energy consumption of pumps and devices.
- Rejection of solar irradiance.

Continuing with the Green Building Studio interface, the model to be analyzed for the BEM predictive simulation is selected, and the file is sent to the Autodesk server to solve the model developed in Revit. Later, the server returns the results to the interface. The Green Construction study is created [50] by obtaining the EUI (energy intensity consumption) to determine the consumption between the developed models and the parameters described above. It is essential to mention the Internet connection quality to send the above file and to avoid the process's collapse. This type of analysis is relevant because Green Building Studio and Insight have cost/consumption/emissions analyses of the analyzed models focused on some of the Sustainable Development Goals (SDGs) of the 2030 agenda, as measured by the United Nations. These include the benefits and adequate planning of buildings, such as taking advantage of resources, materials, processes, quantifications, the environment, and predictions before building. However, the process to obtain the results is a development that the designer can never manipulate again. Regardless of whether the results can be obtained, from this perspective, the use of a server by Autodesk is necessary to run the simulations, which are sent from the file configured for the subsequent sending of the simulation results. Exhibit 5 shows the Green Building Studio interface with the models loaded.

2.3. Toolkit

The Toolkit was developed by the CONDERREF project for the European Union [45]. The results obtained when using the Toolkit correspond to various filters developed under European regulations focused on waste. Additionally, for the proposed methodology, once the quantifications mentioned above have been extracted, their adaptation is developed by converting the volumes of materials to tons in order to enter the data into the program; this is obtained by multiplying the volumes of materials and their specific weight. Once this is developed, the quantities are inserted into the Toolkit. For this purpose and using technical knowledge in construction, the quantifications are classified according to the LER (European Waste List) classification and inserted into the tool. Figure 8 exemplifies the tool's functioning and its composition of the project's Construction and Demolition Waste (CDW) management phases; Exhibit 6 shows the four models developed on the Toolkit.


European Union
European Regional
Development Fund

CONDEREFF
Interreg Europe

Document 1: Summary of project data

PROYECT:	Hostal "El Labradio"		PROYECT TYPE :	DEMOLITION
UBICATION:	QUERETARO MEXICO		ESTRUCTURE:	BALE STRAW NEBRASKA TYPE
ID CATASTRAL:				
SURFACE:	542.54		ENCLOSURES:	COMOON WOOD
RATIO BY ZONE	Jalisco México			
Work Type	DEM	SMH/82/2022	GLAZED SURFACE:	0%
Zone	RML			
WASTE MANAGEMENT	CONTRANSA		Budget item:	51,403,409.00

		TECHINIQUE REDACTION PROJECT PHASE					PROJECT MANAGEMENT CONSTRUCTION PHASE				WASTE MANAGEMENT RCD MANAGEMENT PHASE				FINAL
LER	AUTHORIZED MANAGER	RBD	PFP	RFP	%DFP	JUST	PFC	RFC	%DFC	JUST	PFG	RFG	%DFG	JUST	OKF
RCD: NON STONY NATURE															
ASPHALT															
17 03 02 - Bituminous mixtures other than those specified in the code 17 03 01	SI	0.001	0.585	0.00107826	7.83%		0.785	0.0014469	34.19%	Jus 2-01	0.785	0.0014469	0.00%		0%
Madera															
17 02 01 - Wood	NO	0.009	5.2	0.00958455	6.49%		5.5	0.0101375	5.77%		5.5	0.0101375	0.00%		0%
Plastic															
17 02 03 - Plastic	NO	0.001	0.58	0.00106905	6.90%		0.61	0.00112434	5.17%		0.61	0.00112434	0.00%		0%
Plaster															
17 08 02 - MCO from plasters other than those in the code 17 08 01	CT	0.047	0.3	0.00055295	-98.82%	Jus 1-14	0.3	0.00055295	0.00%		0.3	0.00055295	0.00%		0%
Bricks, tiles and other ceramic tiles															
17 01 02 - Bricks	NO	0.000	0	0	0.00%		0	0	0.00%		0	0	0.00%		0%
17 01 03 - Tiles and ceramic materials	CT	0.360	0	0	-100.00%	Jus 1-19	0	0	0.00%		0	0	0.00%		0%
17 01 07 - Mixture of concrete, bricks, tiles and ceramic materials	NO	0.000	28.5	0.05253069	5.25%	Jus 1-20	30.2	0.0556641	5.96%		30.2	0.0556641	0.00%		0%
CDW: POTENTIALLY HAZARDOUS AND OTHER															
Waste															
20 02 01 - Biodegradable Waste	SI	0.000	0.5	0.00092159	9.22%	Jus 2-22	0.55	0.00101375	10.00%		0.55	0.00101375	0.00%		0%
Others															
020106 Bale Straw		0.000	16.5	0.0304125	304.13%	Jus 2-25	16.5	0.0304125	0.00%		16.5	0.0304125	0.00%		0%

Figure 8. Summary of the Toolkit executed with quantifications in tons and classifications according to LER coding by the European Union.

3. Results

Once the development of the corresponding modeling and simulations is understood, the methodology described in both the Guadalajara model and the Querétaro model is applied, each with the ACS, the TCS, and their respective materials or biomaterials as the case may be, performing both modeling and simulations to subsequently prepare the corresponding comparisons between models and simulations.

Phase 3: Analysis and comparison of both models with ACS and TCS in Energy Plus, Insight, Green Building, and Toolkit.

The models developed for Querétaro with the ACS and TCS systems consider the same geographic data, creating a constant for the simulations that does not compromise the results obtained. Table 3 shows the data considered for both Energy Plus simulations.

Table 3. Information and geophysical data required for simulation in the ACS and TCS systems in the Querétaro and Guadalajara models.

Description	Guadalajara Model with ACS	Guadalajara Model with TCS	Querétaro Model with ACS	Querétaro Model with TCS
Project	House	House	House	House
Location	Guadalajara	Guadalajara	Querétaro	Querétaro
Calculation Time	Saturday, 25 February 2023 01:04 a.m.	Saturday, 25 February 2023 02:47 a.m.	Tuesday, 28 March 2023 11:30 p.m.	Thursday, 28 March 2023 11:41 a.m.
Report Type	Detailed	Detailed	Detailed	Detailed
Longitude	20.48°	20.48°	20.72°	20.72°
Latitude	−103.64°	−103.64°	−100.42°	−100.42°
Dry Summer Temperature	37 °C	37 °C	37 °C	37 °C
Dry Winter Temperature	23 °C	23 °C	23 °C	23 °C
Mean Hourly Oscillation	−4 °C	−4 °C	−4 °C	−4 °C
Mean Minimum Temperature	16 °C	16 °C	16 °C	16 °C

3.1. Energy Plus

In addition, the Energy Plus simulation delivers the global energy consumption produced on the site to carry out the heating and cooling of the building based on the information provided above. Exhibit 6 shows all the simulations developed for Table 4.

Table 4. Revit's data from the Energy Plus extraction in both models and simulated construction systems.

Building Location	Construction Systems	Square Meters of the Building m^2	Maximum Value of Total Refrigeration Load (W)	Maximum Value of Total Heating Load (W)	Refrigeration Charge Density (W/m^2)	Heating Load Density (W/m^2)
Querétaro	ACS	153.15	5906	10,241	38.56	66.87
	TCS	186.69	6955	10,931	37.25	58.55
Guadalajara	ACS	158.05	12,064	11,351	76.33	71.82
	TCS	184.58	13,479	12,429	73.02	67.34

Table 5 shows the models with the lowest energy consumption for interior temperature conditioning in both heating and cooling for Querétaro and Guadalajara, summarizing the most efficient construction systems of the four simulations.

Table 5. Summary of the lower consumption calculated on Energy Plus for the best models of the study.

Building Location	Construction Systems	Square Meters of the Building m^2	Maximum Value of Total Refrigeration Load (W)	Maximum Value of Total Heating Load (W)	Refrigeration Charge Density (W/m^2)	Heating Load Density (W/m^2)
Guadalajara	ACS	153.15	6115	10,241	39.93	66.87
Querétaro	ACS	158.05	12,064	11,351	76.33	71.82

3.2. Insight Simulations of Both Models

The Insight simulation provides the energy consumption of the building. It develops an analysis of the information obtained on the server about similar structures and their consumption in the processes described above. Figure 9 shows the annual consumptions of both models simulated with ACS and TCS.

Figure 9. A comparison of annual consumption in the Querétaro and Guadalajara models with the ACS and the TCS and their costs annually in dollars produced by Insight of Autodesk. Note: The bars that indicate the color of the simulation, which range from blue to red tones and indicate the energy expenditure in dollars according to the standards of the 2030 agenda, being the blue color the one that is closest to the optimal requirements in cost and energy performance, in turn the orange and red color indicate a higher expenditure in energy dollars therefore generates more CO_2.

Once the results of the simulations have been obtained in Insight, it is possible to extract the information from the models with the lowest energy consumption about the cost in dollars per annual square meter for each model. Table 6 shows the prices mentioned in the systems with the lowest cost of the four models developed.

Table 6. Summary of the best values estimated for lower consumption in Insight for the study.

Location	Constructive System	Annual Consumption (USD/m^2/Year)
Querétaro	ACS	22.2
Guadalajara	ACS	89.2

3.3. Green Building Studio for the Querétaro and Guadalajara Models

Up until this section, everything has been developed from BIM modeling and configuration for both the Energy Plus and Insight simulations. Regarding Green Building, the results and quantifications for CO_2 emissions and the life cycle cost, both electrical and fuel, of each model with its construction system are obtained from its server. Table 7 summarizes the results obtained from the process described above.

Table 7. Estimations produced by the Green Building Studio simulation for the Guadalajara and Querétaro models.

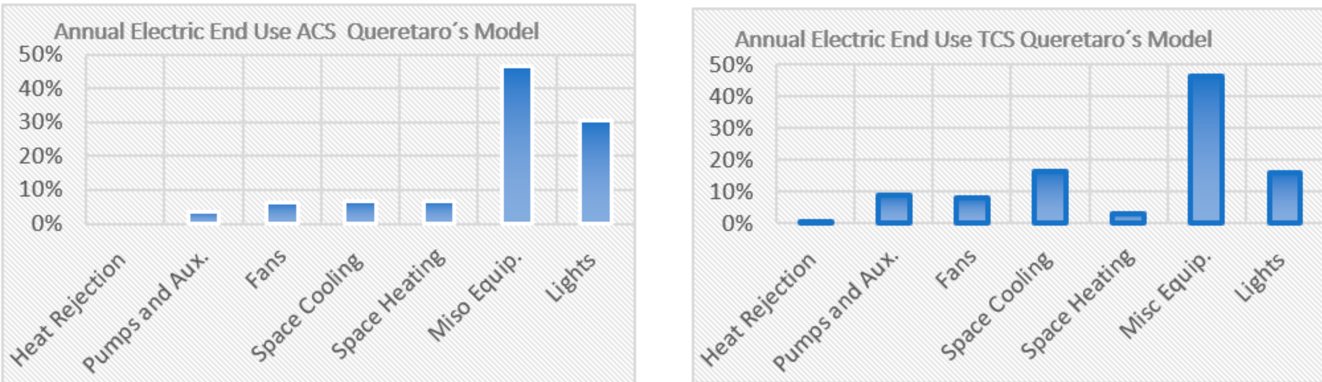
Building Location	Construction Systems	Energy, Carbon, and Cost Summary (Annual Energy Cost USD)	Annual CO_2 Emissions (On-Site Fuel Mg)	Annual Energy Use Intensity EUI (MJ/M^2/Year)	Life Cycle Energy (Electric kW)	Life Cycle Energy (Fuel MJ)
Guadalajara	ACS	2015	0.8	482	484,581	470,327
	TCS	2061	1.2	857	414,423	744,216
Querétaro	ACS	2532	5.7	1763	320,096	3,442,986
	TCS	4634	7.5	2049	732,511	4,517,103

Also, the models with lower consumption and emissions from the simulations can be seen in the Green Building Studio results. Table 8 shows the models with lower consumption and emissions from each simulation in Green Building Studio.

Table 8. Summary of the best values estimated in Green Building Studio for the lower consumption generated in the study.

Building Location	Construction Systems	Energy, Carbon, and Cost Summary (Annual Energy Cost USD)	Annual CO_2 Emissions (On-Site Fuel Mg)	Annual Energy Use Intensity EUI (MJ/M^2/Year)	Life Cycle Energy (Electric kWh)	Life Cycle Energy (Fuel MJ)
Guadalajara	ACS	2015	0.8	482	484,581	470,327
Querétaro	ACS	2532	5.7	1763	732,511	3,442,986

Additionally, Green Building Studio generates the predictive statistics of electrical use intended for the operational performance of the models distributed in percentages; Figure 10a,b graph the final annual consumption of the predictive use of the property.



(**a**) (**b**)

Figure 10. (**a**) The annual electrical percentages of final use in the Querétaro model with ACS. (**b**) The annual electrical percentages of final use in the Querétaro model with TCS.

3.4. Toolkit

Concerning the quantifications of some of the most used materials in the four models described above, they are ordered by the type of construction system and the life cycle of the materials used, each distributed in its recycling, reuse, or transfer phase. Landfill is derived from the respective data obtained, the quantification units are tons, and the tool provides whether the waste is within the permitted quantities according to the contamination ratios or exceeds the estimates made by the tool for its adequate treatment; Table 9 shows the results for the ACS quantifications for the Querétaro and Guadalajara models.

Additionally, Table 10 shows the Guadalajara and Querétaro models; with TCS, the summary reveals the material quantification in tons derived from the product of the material volume by the specific weight of each type of waste involved in the models.

In addition to the quantifications of the Toolkit, it is possible to simplify the data by quantifying the waste in each model with its corresponding construction system to facilitate the analysis of the waste produced by each model. Table 11 shows the mentioned quantifications. The tool does not allow for assigning them as allowed by European regulations.

Table 9. Summary of the quantification of waste materials in tons derived from the product of material volume by specific weight of the Guadalajara and Querétaro models with ACS.

CONDEREFF Interreg Europe Model	Querétaro Model with ACS and Biomaterials			Guadalajara Model with ACS and Biomaterials		
Type of Waste by LER Code	**Recycling**	**Reuse**	**Landfill**	**Recycling**	**Reuse**	**Landfill**
17 03 02 Bituminous mixtures other than those specified in the code 17 03 01	Yes 0.585 Ton	No 0.785 Ton	Yes 0.785 Ton	Yes 0.415 Ton	No 0.615 Ton	Yes 0.615 Ton
17 02 01 Wood	Yes 5.3 Ton	Yes 5.5 Ton	Yes 5.5 Ton	Yes 3.75 Ton	Yes 3.95 Ton	Yes 3.95 Ton
17 02 03 Plastic	Yes 0.58 Ton	Yes 0.61 Ton	Yes 0.61 Ton	Yes 0.4 Ton	Yes 0.42 Ton	Yes 0.42 Ton
17 01 07 Mix of concrete, bricks, tiles, and ceramic materials	Yes 28.5 Ton	Yes 30.2 Ton	Yes 30.2 Ton	Yes 37.8 Ton	Yes 39.8 Ton	Yes 39.8 Ton
20 02 01 Biodegradable Waste	Yes 0.5 Ton	Yes 0.55 Ton	Yes 0.55 Ton	No 1.52 Ton	No 1.72 Ton	Yes 1.72 Ton
02 01 06 Straw	Yes 16.5 Ton	Yes 16.5 Ton	Yes 16.5 Ton	Yes 14.1 Ton	Yes 14.1 Ton	Yes 14.1 Ton

Table 10. Summary of the quantification of waste materials in tons derived from the product of material volume by specific weight of the Guadalajara and Querétaro models with TCS.

CONDEREFF Interreg Europe Model	Querétaro Model with TCS and Common Materials			Guadalajara Model with TCS and Common Materials		
Type of Waste by LER Code	**Recycling**	**Reuse**	**Landfill**	**Recycling**	**Reuse**	**Landfill**
17 03 02 Bituminous mixtures other than those specified in the code 17 03 01	Yes 0.68 Ton	No 0.78 Ton	No 0.68 Ton	Yes 0.51 Ton	No 0.57 Ton	Yes 0.57 Ton
17 04 07 Mix of metals	Yes 4.75 Ton	Yes 4.95 Ton	Yes 4.95 Ton	No 3.7 Ton	Yes 3.9 Ton	Yes 3.9 Ton
01 04 08 Waste gravel and crushed rock other than 01 04 08	Yes 0.56 Ton	Yes 0.58 Ton	Yes 0.58 Ton	Yes 3.5 Ton	Yes 3.7 Ton	Yes 3.7 Ton
17 01 01 Concrete	Yes 45 Ton	Yes 47 Ton	Yes 47 Ton	No 25 Ton	No 27.6 Ton	Yes 27.6 Ton
17 01 07 Mix of concrete, bricks, tiles, and ceramic materials	Yes 17.2 Ton	No 19.3 Ton	Yes 19.3 Ton	Yes 13 Ton	No 15 Ton	Yes 15 Ton

Table 11. Summary of values calculated from the Toolkit for waste management for the lower quantity of waste generated in the models.

Location	Constructive System	Quantified Waste
Querétaro	ACS	0.785 Ton
Model	TCS	20.76 Ton
Guadalajara	ACS	3.835 Ton
Model	TCS	68.17 Ton

4. Discussion

Now, it is true that the simulations developed are only predictive analyses and will never be a reality. However, the development of this type of study generates a lot of certainty in the approximations of reality, obtaining certainty in the approximation and planning of what could be developed and brought to reality. This can be achieved by reducing consumption not only of the buildings and everything related to their context and construction, but also of the waste that they could generate after their life cycle, which can be reintegrated into the environment efficiently and without considerable damage to the natural environment through the use of biomaterials. All the advantages produced by generating this study revolutionize the method of building; however, including traditional construction materials is not a practice that should be ruled out, but the use of biomaterials proves their efficiency in many ways not only for users but also for the environment in general in an economic, social, and environmental way. Below, the most efficient models are shown concerning energy consumption and CO_2 emissions in energy life cycles, both in kWh and fuel consumption.

4.1. Phase 4: Selection of the Best Model Founded

BIM modeling, in conjunction with BEM simulations, carried out in Energy Plus, Insight, and Green Building applied to the models in Revit, yields various results described in this section. Among these, the estimated energy load in the models stands out, showing the quantities in units of watts necessary to cool or heat spaces. The construction systems have lower energy costs for cooling the property and heating in the Guadalajara and Querétaro models. In the simulation with Energy Plus, lower consumption was found in the ACS construction system (biomaterials) compared to the models with TCS (traditional materials). Table 4 shows 5906 watts needed for cooling in the Guadalajara model with DHW and 10,241 watts for heating, contrasting with 6955 watts for cooling and 10,931 watts for heating in the TCS model. In the case of the Querétaro model, 12,064 watts are needed for cooling and 11,351 watts for heating, the consumption being lower compared to the TCS model, with a consumption of 13,479 watts to cool the spaces and 12,429 to heat them in the simulated TCS model. The results responded to a lower energy cost of the models developed with ACS, described in Table 5 and shown in the results section.

Subsequently, when analyzing energy consumption simulations in Insight under the reference with similar buildings, significant reductions in the ACS models compared to those with TCS were also obtained in terms of costs per annual square meter of the described models. The models with ACS obtained better performance compared to the models with TCS: the Querétaro model with ACS produced 22.2 dollars per square meter while the model with TCS produced 40.7 dollars per square meter. Regarding the Guadalajara model with ACS, the simulation produced 89.2 dollars per square meter, while with the TCS model, 92.9 dollars per square meter was obtained, with the ACS also being more efficient in the Guadalajara model. Simplifying the above, the lowest energy costs of the four simulated models correspond to the systems and materials with ACS; the above is noticeable in Figure 9 and Table 6, shown in the results section.

Regarding sustainable construction, the simulation produces predictive estimates on annual energy consumption, CO_2 emissions, building life cycles, and the consumption of construction products. Table 8 shows the models with the lowest consumption produced in the simulated models Querétaro and Guadalajara. When analyzing the TCS and its materials, it is essential to mention the efficiency of the models with the ACS and biomaterials. Making the comparison between the watts necessary to cool and heat the spaces between the DHW systems, the consumption generated is lower than in the models with TCS. Likewise, Green Building analyzes the direct cost in dollars generated by the simulated models, in terms of energy consumption, obtaining from the models with ACS 2015 dollars and 2532 dollars, unlike the cost of the models with TCS that produce 2061 dollars and 4634 dollars. Regarding CO_2 emissions, the models with ACS also show a considerable reduction compared to those with TCS, where the ACS model produces 0.8 Mg and 5.7 Mg, unlike those with TCS which produce 1.2 Mg and 7.5 Mg. Also, in the intensity of energy use it is possible to find the efficiency of the ACS in contrast to the models with TCS; the models with ACS produce 482 MJ/M^2/year and 1763 MJ/M^2/year and the models with TCS produce 857 MJ/M^2/year and 2049 MJ/M^2/year, which shows a considerable reduction in favor of the models with ACS. Regarding the energy life cycle in the Guadalajara model, it was the exception to the trend that has been presented until now; however, in the Querétaro model, this trend does exist, comparing the energy life cycles in the ACS of 320,096 kW and TCS of 732,511 kW. Finally, in the energy life cycle of fuels, the efficiency of the ACS models compared to the TCS was also found, obtaining in the ACS 470,327 MJ and 3,442,986 MJ compared to the TCS with results of 744,216 MJ and 4,517,103 MJ. The above is based on predictive models developed on Autodesk servers. There is a considerable reduction in the models with ACS noticeable in Tables 7 and 8 in the previous results section.

Continuing with the Construction and Demolition Waste (CDWs) and the Toolkit, which identifies the quantification of the waste that does not comply with the current European regulations preconfigured in the Toolkit, the waste of each model is added, and subsequently, with a comparative analysis, considerable decreases are obtained with the amounts of waste found in the models. With ACS, checking the waste reduction based on the materials and amounts quantified for each model, we obtained for the models with ACS 0.785 Ton and 3.835 Ton and in the models with TCS 20.76 Ton and 68.17 Ton. When carrying out the relevant analysis, it is possible to see a broad reduction in the (Construction and Demolition Waste) CDWs in the ACS models with biomaterials; this is shown in Tables 9–11 of the previous results section.

Although the results presented are not accurate but predictive, they facilitate the analysis, planning, and quantification of the developed construction systems and the materials that comprise the four simulated models in the two geographical areas described.

It was found that, considering geographic areas, the ancestral construction systems and biomaterials constitute a highly beneficial tool for decarbonization. As for the materials, the benefit is derived due to the environment in which it is built; this is thanks to the respect and use of the ancestral or typical construction systems of the region, in order to "build without building," facilitating the materials' integration into the environment in a very short period. The above can be verified when advanced design software is used. Although they are not actual data, they are close to solving the problems presented to produce energy efficiency in materials, low energy consumption, and reduced CO_2 and greenhouse gas emissions.

Building without implementing planning entails problems that should not exist today. Simulation and design software such as Revit and their accessories such as Energy Plus, Insight, and Green Building Studio complement almost all construction-related aspects. However, it is essential to emphasize the uncertainty that can be given when developing these simulations because the process is highly automated, and many variables are indeed considered and manipulable. Despite the process to obtain the results raised, we are in favor of the software that has been developed, although the copyright must be obtained and the modeler and simulator must adopt the results based on the coding of simulations; on the other hand, under a superficial analysis it is possible to appreciate the results that have congruence and are reliable. Also, it is possible to contemplate and fully validate the performance of biomaterials compared to the traditional materials used in Mexico; they improve comfort due to their physical and thermal properties, significantly enhancing the performance of the spaces in the homes for their inhabitants. Additionally, by quantifying the waste that will be generated in the future, it is possible to affirm that the buildings will have a low impact on the environment in two ways: the first is due to a lower quantity compared to traditional materials; and the second is because they are biomaterials, so their reintegration into the atmosphere is efficient and easy, avoiding environmental problems in many aspects.

One of the main limitations of this type of analysis is the lack of knowledge, which is why most studies have been carried out in specific economic sectors and only in a few countries, mainly in Europe and Southeast Asia. Examples include China, Japan, Austria, and the United States [19,42,53–56]. For Latin American countries (Venezuela, Bolivia, Brazil, Costa Rica), this environmental assessment is already established in the official statistical information [57–60], but there is still a long way to go. In [61], the authors raise the importance of studying the impact of Latin America in its role as a global provider of resources.

According to the above, it is essential to determine the eco-innovation of materials, waste, and the use of software; for example, in the case of garbage, the program called

Toolkit was developed, which is a tool capable of moving quantitative information about the metabolic functioning of the materials and using BIM qualitatively based on information about land use.

Revit software and its Energy Plus, Insight, and Green Building add-ons are not the only software programs that perform simulations to obtain predictive models of operation, consumption, and modeling optimizations. However, today, they are the most reliable and complete methods for obtaining robust quantifications because they consider many variables for their development. The possibility and scope of generating databases referenced to the geographical areas that consider the variables mentioned in this study will open a vast field of research and work to generate information to use the software more precisely and reliably.

On the other hand, from the industrial revolution and RE approach, this article reports the possibilities and challenges of modeling methodologies for reverse engineering and product quality control to establish an "object-to-object" path. "Model-concept" [62] allowing a future application is key for the design of new products, the modification of existing designs, market analysis for the design and construction sector, industrial inspection, and, of course, the design documentation that provides the traceability of data to adjust details or make improvements that are recorded, updated, and available to be retrieved at any time [63].

Some of the exploratory fields that can be delved into would be the following: (1) Promote research and innovation in the manufacture of materials for industry 5.0 for characterization, modeling, and data science for the emerging needs of the industry of construction under applicable life considerations that can be addressed by design, all towards a greener and digital transition [64]. (2) Delve into the "Reduction of material and energy consumption" (RMEC) by reviewing the current state of the use of CO_2 in construction materials from the perspective of scientific research and commercial applications [64,65]. (3) Evaluate the usefulness of the concept of hybrid construction, as well as the set of techniques and technologies that are derived from it using measurable quantitative parameters [66]. (4) Define eco-innovation as a strategy for processing products, marketing, and organizational innovation applied to city issues, adjusting criteria to GRI [66]. (5) Develop methodologies capable of dealing with manufacturing and applications that facilitate spatial exploration to design more efficiently, reducing physical tests and improving quality and production speed, establishing decision-making systems through conceptualization [67].

4.2. Eco-Innovation, Digitization, and Materials Catalog for BIM

Advanced software for modeling and simulation performs different quantifications based on the coding of the manufacturer's software. However, Revit, for its simulations, is developed under the finite element method to generate results and approximations that are very close to reality, complementing them with the model-corresponding mathematics. Revit uses a processing methodology that utilizes the weather station database and its software source code to produce results for energy consumption, coordinate-based model improvements, and model positioning. However, the data issued are approximations but never a reality, taking into account all the variables that influence the determination of authentic results. Materials and biomaterials have different characteristics depending on a wide variety of factors, from when they are produced to the conditions in which they are manufactured, including relative humidity and many more factors. From this perspective, it is possible to consider the current controversy between the standardization of official construction regulations and geographic regions because each context is different, and the currently established parameters and standards change. These types of problems can be solved through AI by providing feedback on more specific conditions and parameters to cover the variables discarded in the current software to obtain accurate results. Regardless of whether AI technology is currently a possibility to be developed or not, the work of inter- and multidisciplinary teams must be a reality in any project. The above is indisputable due to the versatility of the developed projects and the variables to be considered. In addition, interdisciplinary work is necessary in order to understand how to obtain results that are more accurate and closer to reality.

4.3. Technological Reconversion and the Revolution of Industry 4.0 and 5.0

Energy and materials have a continuous and mutually enriching relationship. Materials produce energy or allow energy to be transferred into valuable forms. Power, in turn, has made possible the production of a wide range of materials for society [68]. Meanwhile, for their part, professionals may pursue sustainable innovation without considering the cost and effort required to achieve the result of innovation. Recent studies indicate that the purposes related to sustainability are positioned within innovation, seeking to reduce the negative impact on the environment, reduce the consumption of materials and energy, and improve working conditions in terms of health [64,69,70].

In understanding this scenario, the results of the case study essentially correspond to the findings in the literature and involve three relevant approaches for the advancement of research: the first one is related to digitization and 3D modeling systems, the second one consists of the vision of reverse engineering, and the final one puts into consideration the concept of Hybrid Building Technology with an emphasis on materials and biomaterials.

In this sense, reconstruction methods based on typing or 3D modeling appear as paths supported by Industry 4.0, 5.0, and Reverse Engineering (RE). Industry 4.0 proposes a design method for the creation or re-creation of new products from existing and sometimes obsolete products and thus determines their characteristics, functions, design details, construction, and operation to reproduce them and in what possible ways to improve them [63,71], all through the use of digital manufacturing. From industry 5.0 with the modeling of materials, their characterization, and computing, the integration of such methods is proposed as a crucial aspect of ontologies from different domains and protocols that facilitate computational and experimental efforts for the digitization of materials, which, combined with advanced data science tools (including machine learning and artificial intelligence), can develop digital, standard, usable, and compatible solutions in the domain of modeling and the characterization of different materials [61]. Subsequently, reverse engineering is used to acquire knowledge that has been lost, obsolete, or poorly retained. It establishes a paradigm shift that contrasts traditional advanced engineering that uses logic, mathematics, and abstract ideas and transforms them into physical products. Our system is similar to the Reverse Engineering (RE) concept, which separates a physical product or system from a digital model [72].

In a strategic complement to this digital manufacturing scenario, the Hybrid Building Technology proposed by [73] combines the advantages of two construction methods, the modern one with better mechanical performance and economic efficiency and the traditional one that demonstrates improved bioclimatic characteristics. From an ecological position, its research scenario of case studies demonstrates whether this results in less pollution. As a result, biomaterials are capable and competitive in reducing the impact of construction on the environment.

These obtained results, complemented by other research [73–76], suggest that it is a priority to address the following: (a) the establishment of new standards of characterization and change in the Unified System based on the performance of materials and biomaterials that ensure that the industry can benefit from a breakthrough with a high degree of replicability and confidence, as well as new tools to anticipate or simulate the long-term performance of these unique components; (b) the advanced and computer characterization of materials that require "machine-driven" data development and analysis, from the comparison of construction codes and standards with materials and biomaterials based on our own indicators for urban metabolism and the decarbonization of the city and buildings that allow for the realization of the digitalization of the development of materials to achieve the green transition, based on an integrated system to define the optimal, that is, cost, time, and resources; and (c) the model-based definition necessary for component design changes, which must be established on digital specifications that link the microstructure and evaluation of mechanisms, geometric characteristics, and the specific location of properties with manufacturing process routes for the optimization of process design for industrial applications aimed at balancing ecology and efficiency.

The above leaves us in a field of possibility that, for the fulfillment of the SDGs and the 2030 Agenda, allows us to limit our needs by adopting hybrid approaches through the mixture of materials to develop sustainable materials that satisfy the demand with a low carbon footprint, as well as to integrate modern construction processes with traditional approaches to increase competitiveness and adopt hybrid approaches to architecture and urban planning that offer great ecological potential compared to conventional styles [74].

In concluding our discussion, it is pertinent to recognize that the cultural dimension is an intrinsic factor in analyzing urban metabolism through the MuSIASEM methodology. Cultural aspects inform and shape architectural space production, significantly influencing cities' metabolism. These cultural factors reflect historical and contemporary practices and impact urban sustainability and decarbonization, as evidenced in [76]. Incorporating culture into the advanced use of simulation software could reveal new insights into sustainable urban planning, aligning carbon-neutral strategies with local traditions and values. Therefore, we propose expanding the current research framework to include urban planning scenarios that integrate cultural aspects, which could enrich the mosaic of sustainable urban transformation and provide a vital component for a holistic understanding of urban metabolism.

5. Conclusions

The results of this study demonstrate some of the BIM approaches used in the study of social systems, in MuSIASEM, and in Environmental Approaches. All of these design methods require the development of environmental mitigation measures. However, so far, they have faced some problems, such as the lack of knowledge about energy use, especially in social work, because they only focus on the analysis of bioenergy without examining how we live, affecting other species and social groups. More professional support must be provided in defining architectural symbols and the entire design. To achieve this, this aspect is strengthened and contributes significantly to the organicity as other elements do.

The identification, calculation, and analysis of the flows of matter and energy constitute the methodological center for determining the metabolism of an urban system since, with these flows, "the movements of the goods and substances of a city can be monitored from the surrounding and supply environment, through production and consumption and back to the air, water, and soil compartments" [77]. In this way, the scope of the results seeks to establish a path towards constructing a methodology that responds to the challenges of urban decarbonization and construction where the configuration of biomaterials in 3D modeling and digitization tools allows for anticipating scenarios. These results are minimally acceptable for reducing environmental impacts associated with the housing supply case study in response to the location conditions in its bioregion.

The BIM methodology is applied to complex systems and biomaterials from urban metabolism towards decarbonization, starting from 3D Modeling and digitization in service of the sustainable construction of buildings (Green Building Construction). Subsequently, a comparative analysis of two cases is made. For the study located in the states of Jalisco and Querétaro, Mexico, in order to obtain the operational energy consumption linked to the materials used for their construction, both buildings are simulated in different geographical areas and with two different construction systems. Obvious advantages are obtained when biomaterials are used to replace common materials such as concrete, that is, the operational energy consumption of the home is significantly reduced. Therefore, in terms of costs, energy services are positive, as is the reduction in CO_2 emissions. The results of the models, simulations, and the Toolkit tool show the advantages of biomaterials in contrast to commonly industrialized materials. Furthermore, using the Toolkit can reduce direct environmental damage by using reuse and recycling practices, regardless of whether a remodeling or construction project is involved.

On this aspect, it is essential to utilize new technologies to achieve more accurate planning, regardless of the nature of approximation. The methodology offers quantification precision through BIM modeling and configuration, and BEM simulations provide very accurate predictions. Based on weather stations and unifying the data with the configuration of BIM biomaterials, the simulations result in efficient models in every sense. Furthermore, with the quantifications of the models applied to the Toolkit tool, it is possible to plan the life cycle of the building's waste and the relevance of its destination, whether recycling, reusing, or transferring to a landfill.

The primary objective of this study is to provide a comprehensive understanding of the dynamic landscape of construction and demolition resources, materials, and waste management strategies. This study's comprehensive examination of the changing terrain of construction waste use strategies and tools sets this study apart.

In addition, the present research aims to contribute valuable information to sustainability, resource utilization, urban metabolism, and construction and demolition waste management, fostering a deeper understanding of the multifaceted challenges and opportunities within this critical area. Policymakers, environmentalists, and industry stakeholders can use these findings to develop and implement improved practices in project execution and managing construction and demolition waste, promoting sustainability and resource efficiency [78].

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