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TOOLKIT FOR THE EFFICIENT ARTICULATION OF SUSTAINABLE STRATEGIES WITH DESIGN AND MANAGEMENT METHODOLOGY USED BY AECO INDUSTRY IN LATIN AMERICA

Carolina Valbuena-Bermúdez[a,*], Claudia Bengoa-Alvarez[b]

[a] *Pontificia Universidad Javeriana, Faculty of Architecture and Design, Department of Architecture, Edificio 16 / Carlos Arbeláez / Cra. 7 No. 40–62, 110231 Bogotá, Colombia*

[b] *Politecnico di Torino, Faculty of Architecture, Department of Architecture and Design, Corso Duca degli Abruzzi 24, 10129 Turin, Italy*

[*] corresponding author: valbuenas@javeriana.edu.co

Abstract. Digital transformation is changing the world, and with it the construction and architecture industry, however, although there are many collaborative work frameworks for digitization, and agile philosophies among different professionals, the methodologies of creative processes throughout the entire life cycle of a project that involves sustainability strategies have been greatly reduced and relegated over time. Latin America has the highest levels of biodiversity, a wide variety of climates, a range of implementations and sustainable opportunities that have been sidelined versus the speed of innovation in construction projects, in this context, the design philosophy based on nature must be implemented as a premise from leaders to developers, regardless of the management method used. This document studies the sustainable construction progress in five Latin American countries, analyzing climatic, regulatory and socioeconomic aspects, with the aim of increasing processes efficiency towards better sustainable constructions. Consequently, it proposes a methodology for the creation of an effective sustainable tool which works hand in hand with information systems and synchronous digital collaboration (BIM, VCD or IPD), in order to improve the design and management of sustainable projects throughout their life cycle through specific design strategies and design guidelines for each city, using the cities of Buenos Aires, Brasilia, Santiago, Bogotá and Lima as a case study.

Keywords: Sustainable design, digital transformation, AECO, design and management methodologies, efficiency, Building Information Management, sustainable certifications.

1. Introduction

The potential that technologies grant for the development of design and construction projects is enormous if articulated with the sustainability requirements to be implemented in different buildings. The construction sector has become progressively interested in the creation of high energy and performance buildings with a reduced carbon footprint and environmentally friendly architecture, but these projections are mainly made in the final phase of the design stage where many of the parameters, components and elements have already been chosen under generalised parameters without specificities, especially for the Latin American context. It is therefore essential to develop a sustainable methodology, integrated throughout the life cycle of projects, that allows conscious decision making from the outset, the selection of different design alternatives that respond appropriately to the site context, and efficient responses to all the studies involved for the settlement site. Even today it has not yet been possible to fully integrate the evaluation of environmental parameters in parametric BIM models throughout the entire construction life cycle, therefore this article focuses on the use of environmental parameters that are not generalised but rather specific topographic, environmental and climatic as necessary criteria for the Latin American context and to give a much more precise response to the buildings to be constructed in this region.

2. Sustainable strategies and its relation with design and management methodologies in Latin America

2.1. Articulation between digital transformation and sustainable design

The Architecture, Engineering, Construction and Operations (AECO) industry projects are characterised by low technological innovation and little improvement in productivity rates, and seem to lag far behind the latest technological trends in other industries. Most production processes in the construction industry are traditionally manual or craft-based, organised with simple management tools and little incorporation of technology [1].

This lack of automation and limited digital transformation explain not only the low productivity performance compared to other industries and the limited development of countries in terms of Gross Domestic Product, but also the high environmental impact due to the production of large amounts of raw materials, low carbon footprint offsetting and a strong impact on environmental sustainability and the circular economy and thus on the quality of spaces such as homes and offices and people's well-being [2].

This assessment is common in the analyses carried out by associations that evaluate the performance of the sector in different Latin American countries, where the problems in the planning and execution processes are demonstrated. Thus, in recent years, the sector has undergone significant changes driven mainly by the implementation of new technologies and collaborative frameworks that have enabled the optimisation of various on-site processes, improving the management of communication and planning based on data analysis and information capture. BIM, for example, has become the articulating hub of the building project life cycle for performance analysis requirements, planning, scheduling, costing, data organisation and the provision of construction documents, in addition to design, visualisation and sustainability parameters. By providing a three-dimensional (3D) representation of a project that includes all its component parameters, Building Information Modelling (BIM) facilitates integration, interoperability and collaboration in the construction industry [3].

This is how resource scarcity, sustainability challenges, stricter regulations and decrees for recycling and efficiency of all resources in buildings motivate the Architecture, Engineering, Construction and Operation (AECO), Facility Management (FM) and deconstruction sectors to manage resources efficiently [4].

2.1.1. Design and management methodologies used by AECO industry

Policies, laws and regulations around the world are now requiring the sector to embrace sustainable innovation in terms of products and processes to foster more sustainable outcomes [5, 6] and more productive outcomes for the AECO industry. There are several project management methodologies that today have evolved and provided greater interoperability throughout the project lifecycle [7].

BIM is ideal for providing information to improve the design and performance of buildings in relation to sustainable building design with Integrated Project Delivery (IPD) and design optimisation [8] efficiently in the early stages of the process, and produce an improved and compatible solution between all specialties involved.

Information exchange requires a software environment in which software can exchange data automatically, independent of the software and the location of the data.

The trend in the construction industry has been to focus not only on time and cost savings, but also on environmentally friendly buildings that can provide high performance, in order to maintain the level of achievements so far requires the development of more sophisticated and robust platforms that address not global and generalised parameters, but specific climatic and site contexts [9].

2.2. Sustainable Construction in Latin America

In Latin America, buildings are estimated to consume 22 % of the region's total final energy demand. Estimates for the region suggest that energy demand will increase by at least 80 % by 2040, compared to current demand, driven by an expanding middle class [10]. Considering also that 80 % of Latin America's population lives in cities, where the largest increases in energy demand and growth in built-up area are expected, it is necessary to ensure that this does not result in an overall growth in carbon emissions, therefore it is crucial to take into account that buildings, as major carbon emitters, play a key role in mitigating the effects of climate change from the construction stage, throughout their lifespan and until the end of their life cycle.

In the following, the progress of sustainable construction in 5 Latin American countries with different climates is analysed, reviewing their laws, regulations, and socio-economic aspects; to determine which deficits do not allow the efficient articulation of sustainable strategies with the methodologies used by the construction industry.

2.2.1. Sustainable regulations: Case Study of Argentina, Brazil, Chile, Colombia and Peru

Latin American countries are situated in a context of population growth, economic crisis and lack of planning, this has been reflected in the sustainable construction aspect, however, norms and regulations are beginning to be implemented [11].

Each country has a different progress in terms of sustainable construction, in the region, Brazil stands out as the country with the fourth highest number of LEED-certified buildings in the world. Brazil has also developed a new certification for residential buildings and single-family homes, through a course based on laws, climatic and construction conditions specific to the country's locations [12].

In Argentina, the government developed public policies in favour of sustainable construction through the Ministry of Environment and Sustainable Development, and also incorporated a sustainable housing manual, which addresses issues from project location to construction and energy consumption, providing recommendations to help improve environmental performance.

Since 2012, Chile has had a housing energy rating system in place, enacted by the Ministry of Housing and Urban Development, which functions as a voluntary tool to assess the energy efficiency of a new home during its period of use. This system, allows to evaluate from individual houses to residences and compare the percentage of energy savings compared to the standard house. Chile has positioned itself as a benchmark in comparison to other countries in the region as it has promoted improvement in regulations in relation to sustainability in construction, however, public policy was not adapted to local regulations and a large part of the infrastructure was built under standards of countries with different social and geographical conditions [12].

In Colombia there are regulatory documents that support sustainable construction, such as the Macro project for Social Housing, which proposes the use of thermal materials, efficient lighting and official appliances. The macro project is implemented by the national government through the Ministry of Energy and Mining, the Ministry of Environmental and Sustainable Development, as well as the Ministry of Housing, City and Territory, and private institutions. Nevertheless, the lack of supervision mechanisms means that it is up to the builder to decide whether to apply sustainability practices in their construction projects or not [12].

Peru is still at an early stage in the incorporation of energy efficiency measures; in terms of regulations, there is the National Environmental Management Plan 2011–2021 of the Ministry of Housing, Construction and Sanitation, which establishes mechanisms for environmental monitoring and control of activities related to construction, urban planning and sanitation. In conjunction with the ministry, the National Directorate of Construction is in charge of approving environmental impact studies and issuing environmental certifications [12].

In general, in many Latin American countries there is lack of interest in the construction sector in the field of sustainability, as the interventions executed respond more to the pressure of international norms and agreements rather than to their own commitment. There is also a lack of strategy to develop a clear policy defining the concepts of sustainable development.

2.2.2. Social Study: Social housing programs vs sustainable certified buildings

To understand the social study, it is necessary to analyse the Sustainable Social Housing Programmes used in low social class buildings, and the Sustainable Certifications usually used in middle or upper social class buildings.

In terms of Sustainable Social Housing Programmes, it can be mentioned that, in Argentina, the Global Environment Facility project, called "Energy Efficiency and Renewable Energies in Argentinean Social Housing" has the main objective of contributing to the reduction of greenhouse gas emissions by reducing energy consumption in social housing [13]. Brazil has made significant progress in the development of voluntary sustainable building certification standards adapted to the local context, specifically for the social housing sector, the certification tools are "Selo casa azul da Caixa" and "Aqua process" [13]. Chile is one of the most advanced countries in terms of sustainable social housing, the energy efficiency projects implemented and the Housing Energy Rating System position the country as a regional pioneer [13]. In Colombia, the Colombian Council for Sustainable Construction created the CASA Colombia certification system for sustainable social housing, this system highlights projects that, beyond the rational use of energy and water resources, are committed to well-being, social responsibility, sustainable management of construction processes, understanding of the environment and the specification of materials with big attributes regarding their environmental and social impact [14]. Finally, Peru is still behind both in the development of sustainable construction policies for the social sector and in the implementation of energy efficiency measures in the sector; however, it is possible to mention some strategies that have been developed, such as the Sustainable Construction Code whose implementation will be gradual over time, as well as the social housing programme "Mi Vivienda" in which a green bond is granted [13]. Regarding Sustainable Certifications used in middle and upper social class buildings, the sustainable certifications analysed will be LEED, EDGE, BREEAM and WELL, of which Argentina and Peru have LEED and EDGE certified buildings, Brazil has LEED, EDGGE, BREEAM and WELL certified buildings, Chile has LEED, EDGE and BREEAM certified buildings, while Colombia has LEED, EDGE and WELL certified buildings.

3. Materials and methodology

According to what has been analysed, the articulation between design and management methodologies and sustainable design is produced through the plugins that are installed in design programmes. Nonetheless, as these programmes are used by different construction professionals, on many occasions there is a range of options for sustainable analysis and it is not known which are the best strategies to use for each city. On the other hand, it has been observed that sustainable regulations, as well as those for social housing in Latin America, are still in the process of being drawn up, which means that there is no comprehensive analysis of sustainable design, but only of the points indicated in the regulations, generating a partial analysis. In terms of sustainable certifications, the building is often designed and then adapted through a consultancy to achieve certification, generating one of the main problems that have been analysed, which is not considering sustainability from the first moment of the building's design. Taking this problems into consideration, the answer is that it is necessary to improve the sustainable plugins used in design and management programmes, creating a new climate analysis tool/plug-in that allows us to select the city where

			Argentina B. Aires	**Brazil** Brasilia	**Chile** Santiago	**Colombia** Bogotá	**Peru** Lima
Data	Elevation	m	25	1172	570	2640	0–1550
	Latitude	°	34.82° S	15.87° S	33.38° S	4.7° N	12.0° S
	Longitude	°	58.53° W	47.93° W	70.78° W	74.13° W	77.1° W
Design strategies (ASHRAE Standard 55)	Comfort	% of hours in the year	10.51	15.05	12.56	1.49	9.57
	Sun shading of windows		7.92	16.16	8.79		8.31
	High thermal mass				5.00		
	High thermal mass night flushed		2.17	6.81			
	Natural ventilation cooling		1.69				
	Internal heat gain		31.03	24.3	27.45	49.31	44.13
	Passive solar direct gain high mass		14.99	11.89	17.87	10.41	8.19
	Wind protection of outdoor spaces		0.08				
	Dehumidification only		9.38	21.26	0.12		27.97
	Cooling, add dehumidification if needed		4.32	3.69	0.10		1.83
	Heating, add humidification if needed		17.91	0.84	28.11	38.79	

TABLE 1. Design strategies (ASHRAE standard 55) for 5 Latin American cities.

sustainable design is being worked on and that automatically teaches us the design strategies and design guidelines to follow, allowing us to design the building having the information from the beginning, considering all the sustainable strategies that benefit it. To this end, the following methodology is proposed: "Creation of a more effective sustainable plugin for Latin America" (Figure 1):

In order for the proposed plug-in to provide Design Guidelines, the following steps were followed:

Using `http://climaplusbeta.com/` developed by Christoph Reinhart (MIT Sustainable Design Lab), the climatic data of each city is analysed, for this to happen it is necessary to enter an Energy Plus Weather (EPW) file on the website; the file, obtained from the opened database of the U.S. Department of Energy, has hourly measured data in IWEC format.

The EPW file creates a Psychrometric Chart with the hourly measured data graphically printed. The chart contains a temperature-humidity cartesian coordinate system, so each hourly condition of a year is represented by a point. Each point is plotted by its x-coordinate (temperature) and y-coordinate (humidity ratio) [15].

After that, to determine the thermal comfort area, the Thermal Comfort Model ASHRAE 55 and Current Handbook of Fundamentals is used, this tool can be applied in developed and developing countries [16], the model defines the thermal comfort area on its standards, and the area is graphically represented in the Psychrometric Chart.

The hourly measured data outside the thermal comfort area, can become comfortable, using the Givoni-Milne Bioclimatic Chart Strategy, where different design strategies are represented by specific zones in the Psychrometric Chart. For this to happen the hours that are located in the comfort zone and in each design strategy zone must be identified, the percentage corresponding to each zone must be calculated, where 100 % are the 8766 hours in a year [15], design strategy zones with the highest percentage must be prioritized in order to get a higher number of comfortable hours.

Finally, the writing of design guidelines is focuses on the work of Ligget-Milne, they developed design guidelines that respond to the design strategies zoned by Givoni-Milne; however, we have adapted the Design Guidelines to the Latin American context, considering their location in another hemisphere, their diverse topography, and the different social context of its application. The design guidelines adapted to the context have been numbered from 1 to 18 (the first having the highest priority) and are correlated with design strategies, in such a way that the first design guideline will be a response to the design strategy with the highest percentage.

4. Discussion and results

As results, Table 1 "Design Strategies" of five Latin American cities is presented, obtained from the analysis of the Psychrometric Chart of each city, as can be seen in Figure 1, each strategy has been given a percentage that is related to the importance of the implementation of that strategy. The percentages in Table 1 are translated into Table 2 "Design Guidelines" where a set of guidelines are numbered from 1 to 18, with the number 1 corresponding to the most important design guideline. With this example of five Latin American cities to which methodology has been applied, it is demonstrated that this analysis can be performed for any city in Latin America, providing design strategies and design guidelines that allow for a more accurate and user-friendly sustainable plugin.

5. Conclusion

Sustainable strategies are commonly implemented in the final design phase by the Latin American AECO industry. However, many of the building parameters and elements have already been defined in previous stages and cannot be modified. The use of the methodology proposed by the climate analysis tool/plug-in complementary to BIM, which automatically provides

Design Guidelines	**Argent.**	**Brazil**	**Chile**	**Colom.**	**Peru**
	B. Aires	Brasilia	Sant.	Bogotá	Lima
Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, well insulated.	1	3	3	1	1
For passive solar heating face most of the glass area north (south in Bogotá) to maximize winter sun exposure, but design overhangs to fully shade in summer.	2	4	1	4	12
Provide double pane high performance glazing (Low-E) on west, south, and east, but clear on north for maximum passive solar gain.	3	17	2		
Traditional passive homes in temperate climates used light weight construction with slab on grade and shaded outdoor spaces.	4	1	6		2
Use high mass interior surfaces like slab floors, high mass walls, to store winter passive heat and summer night “coolth”.	5	14	4	6	
Sunny wind-protected outdoor spaces can extend living areas in cool weather (seasonal sun rooms, courtyards, or verandahs).	6		7	5	9
Traditional passive homes in cool overcast climates used low mass tightly sealed, well insulated construction to provide rapid heat buildup in morning.	7		8	3	5
Organize floorplan so winter sun penetrates into daytime use spaces with specific functions that coincide with solar orientation.	8		5	11	
In this climate, shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter.	9	5	10		4
Trees should not be planted in front of passive solar windows but are ok beyond 45 degrees from each corner.	10		9	15	
Low pitched roofs with wide overhangs works well in this climate.	11	12	14		7
Window overhangs or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning.	12	7	17		16
Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy.	13		11	8	
Long narrow building floorplan can help maximize cross ventilation in temperate and hot humid climates.	14	10			15
Good natural ventilation can eliminate air conditioning if windows are well shaded and oriented to prevailing breezes.	15	9			14
Screened porches and patios can provide passive comfort cooling by ventilation in warm weather.	16	2			3
Locate garages or storage areas on the side of the building facing the coldest wind to help insulate.	17		13	17	
High efficiency furnace (Energy Star) should prove cost effective.	18		12	7	
Use plant materials (bushes, trees, ivy-covered walls) especially on the west to minimize heat gain.		6			8
Traditional passive homes in hot humid climates used light weight construction, and shaded outdoor porches, raised above ground.		8			
Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain.		11			18
Shaded outdoor buffer zones (porch, patio, lanai) oriented to the prevailing breezes can extend living and working areas in warm or humid weather.		13			11
On hot days, indoor air motion can make it seem cooler by 2.8 °C or more. Natural ventilation can store nighttime “coolth” in high mass interior surfaces, to reduce or eliminate air conditioning.		15			
Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain.		16			
In wet climates well ventilated attics with pitched roofs work well to shed rain and can be extended to protect entries, verandas, outdoor work areas.		18			10
If a basement is used it must be at least 0.46 meters below frost line and insulated on the exterior or on the interior.			15		
Small well-insulated skylights (less than 3 % of floor area in clear climates, 5 % in overcast) reduce daytime lighting energy and cooling loads.			16	13	
High mass interior surfaces (stone, brick or adobe) feel naturally cool on hot days and can reduce day-to-night temperature swings.			18		
Glazing should minimize conductive loss and gain (minimize U-factor) because undesired solar radiation gain has less impact in this climate.				2	6
Extra insulation might prove cost effective, and will increase occupant comfort by keeping indoor temperatures more uniform.				9	
Traditional passive homes in cold clear climates had a central heat source, south facing windows, and roof pitched for wind protection.				10	
Super tight buildings need a fan powered HRV or ERV (Heat or Energy Recovery Ventilator) to ensure indoor air quality while conserving energy.				12	
Windows can be unshaded and face in any direction because any passive solar gain is a benefit.				14	
Insulating blinds, heavy draperies, or operable window shutters will help reduce winter night time heat losses.				16	
Use vestibule entries (air locks) to minimize infiltration and eliminate drafts, in cold windy sites.				18	
Raise the building high above ground to minimize dampness and maximize natural ventilation underneath the building.					13
High Efficiency air conditioner or heat pump (at least Energy Star) should prove cost effective in this climate.					17

Table 2. Design Guidelines for 5 Latin American cities.

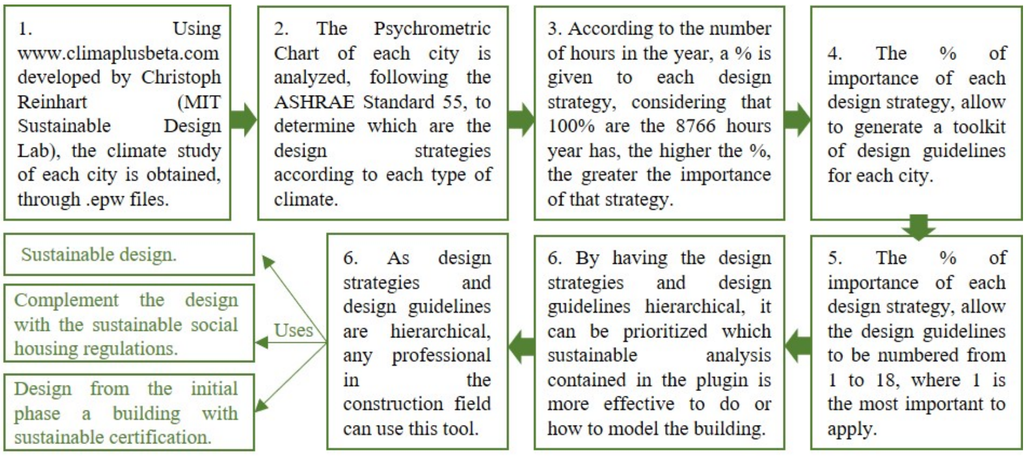

Figure 1. Methodology “Creation of a more effective sustainable plugin for Latin America”.

a set of site-specific, easy to understand and apply design guidelines, would ensure the implementation of sustainable strategies from the first design phase, allowing conscious decision making, obtaining a better sustainable design, and optimising the other stages of the life cycle, such as execution, operation and demolition.

Most of the plug-ins that integrate sustainable strategies and parametric BIM models perform analyses of general characteristics and provide extensive information without the user knowing which one to use. The proposed plug-in analyses specific parameters, such as climate data, latitude, longitude and altitude of Latin American cities, it has an integrated database of EPW weather data files. Additionally, it automatically displays the data of the searched city and processes it according to the established comfort parameters thus generating a guideline of effective design strategies for that city.

BIM is a methodology of Integrated Project Delivery and Design Optimization, and professionals from different specialties work on it. The proposed plug-in, being simple to understand, can be used by experts and by any type of professional in the AECO industry, allowing them to easily recognize the main design guidelines and apply them to the project throughout its life cycle, which is currently a limit, given that the existing tools require significant analytical expertise in the field of sustainability.

Sustainable construction laws and regulations are on the process of development or do not exist in Latin America; many of the current regulations are optional, focused on the analysis of a single aspect, or are created under the standards of other countries, which do not allow the effective design of sustainable buildings. Having taking this into consideration, the proposed plug-in allows each professional to independently analyse what other strategies would be effective to apply in each city to complement and improve the strategies proposed by the regulations.

The Sustainable Social Housing Programs for the low-income population focused on the fulfilment of specific sustainable strategies, such as reducing energy consumption. The proposed plug-in allows the recognition of passive design guidelines that do not generate extra cost in the design, thus complementing the strategies proposed by the social programs.

To achieve Sustainable Certifications in middle or upper class buildings, usually the project is carried out and then a specialised company is hired as a consultant in order to make adjustments to achieve the certification; with the proposed user-friendly plug-in, the user can implement the sustainable design according to the certification standards from the very first stage.

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