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EDITORIAL

Almost six months have passed since the publication of our last issue in June 2019, when nothing presaged the scenario we are living in the country today. A convulsed Chile, which experiences an unprecedented social explosion, result of a multidimensional and historical crisis originated mainly in an abysmal social, economic and environmental inequality, fundamental pillars of the principles of sustainability.

Chilean society demands profound changes in the way we have been developing as a country. In that context and as result of visible demands and social mobilizations, the Chilean political class has signed an Agreement for Social Peace and New Constitution promoting for the month of April 2020 a plebiscite, which would allow democratically decide if Chile wants or not a new constitution. This will undoubtedly point to a historical milestone: the possibility of rethinking our Constitution, an unthinkable issue six months ago and which I relive here as one of the most important events of the last 30 years since the return to democracy.

This scenario, which brings with it high expectations of making substantial progress on profound sustainability issues, makes it necessary to refer to the poor results of the long-awaited COP25; the most important summit of climate action organized and chaired on this occasion by Chile, which beyond the scopes known through media, failed to reach relevant agreements on the matter and evidenced the lack of greater ambition in mitigation, adaptation and financing to combat imminent climate crisis that affects us globally. Although it is true that certain agreements were reached - better said, more demanding voluntary declarations - for an important part of the scientific, academic and civil community, the results of the expected summit constitute a frank setback, which puts us at a level of progress comparable to what was previously contained in the Paris Agreement of 2015. Accordingly, no concrete short-term actions are envisioned for the 1.5°C reduction of global temperature increase, a framework in which one of the most anticipated and controversial actions was the approval of regulations on the markets of coal, as well as tacit mechanisms for financing losses and damages linked to the climate crisis. In short, we will have to wait for the proposals and results of the year 2020 in Glasgow, meeting for which already over 80 countries, including Germany, France, Spain and the UK, have pledged to present "harder" plans, but in which the expected signals from China, US, India and Russia continue to be absent, nations that together contribute more than 55% of GHG emissions.

Faced with this challenging local and global panorama, we invite you not to fall into perhaps justified pessimism but, on the contrary, to persist in the contribution from our paths to the construction of a more equitable society in all dimensions, where the habitat and built environment must be harmoniously combined.

I close this editorial presenting a large and varied repertoire of eight articles by Latin American authors from Chile, Spain, Colombia and Argentina, which were rigorously selected and represent solid contributions to knowledge for sustainable development.

Finally, I express, as usual, my sincere gratitude to all the authors and reviewers who have trusted HS and also to the permanent commitment of the editorial team: Dr. Olga Ostria in her role as Corrector of Style, Eng. Jocelyn Vidal as Editorial Producer, Eng. Karina Leiva in Computer Support and Architect Ignacio Sáez in Diagramming.

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LIVING IN A SACRIFICE ZONE: A MULTI-SCALE ANALYSIS OF PUCHUNCAVÍ DISTRICT, CHILE

HABITAR EN UNA ZONA DE SACRIFICIO: ANÁLISIS MULTIESCALAR DE LA COMUNA DE PUCHUNCAVÍ

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RESUMEN

El presente artículo expone los impactos que el desarrollo del Complejo Industrial Ventanas (CIV) ha tenido en la comunidad de Puchuncaví, entendiendo este como origen y causa de la crisis socioambiental de la denominada "Zona de Sacrificio". A partir de autores como Lefebvre (2013) y Augé (1993) y sus planteamientos sobre la coproducción del espacio y el no lugar, se realiza un análisis multiescalar que persigue sentar las bases para la discusión y argumentación de una planificación basada en la comunidad y sus experiencias. Consecutivamente, se propone una metodología consistente en un taller participativo con miembros de la comunidad, cuyo objetivo es identificar, reconocer y caracterizar tanto el habitar en esta zona, como también los impactos que el desarrollo industrial ha tenido en el territorio. En definitiva, se observa que los actuales Instrumentos de Planificación Territorial perpetúan las lógicas de reproducción de la Zona de Sacrificio, impactando negativamente en la identidad territorial de la población de Puchuncaví, identidad que es validada por la comunidad. Finalmente, se abre la discusión sobre la necesidad de nuevas racionalidades que impliquen la revaloración del territorio, y su consiguiente reapropiación, como lógicas catalizadoras de propuestas productivas divergentes a la que hoy se encuentra materializada en el CIV.

Palabras clave
contaminación ambiental, planificación territorial, identidad comunitaria, zona de sacrificio.

ABSTRACT

This article presents the impact the development of the Ventanas Industrial Complex (VIC) has had on the Puchuncaví (Chile) community. The VIC is understood to be the origin and cause of the socio-environmental crisis of this so-called Sacrifice Zone. Based on references such as Lefebvre (2013) and Augé (1992), and their approaches to the co-production of space and non-place, a multi-scale analysis is carried out that seeks to lay the foundations for the discussion and argumentation of planning based on the community and its experiences. Subsequently, a methodology consisting of a participatory workshop with members of the community is proposed that aims to identify, distinguish and characterize living in this area, in addition to the impact industrial development has had on the territory. The conclusions reveal that the existing Territorial Planning Regulations perpetuate the logic behind the development of the Sacrifice Zone. This negatively impacts the regional identity of the residents of Puchuncaví, which is validated by the community. Finally, the article opens the discussion on the need for new rationales that imply the (re)valuation -and the consequent (re)appropriation- of the territory as catalytic logics for productive proposals that diverge from that currently embodied in the VIC.

Keywords
environmental pollution, territorial planning, community identity, sacrifice zone.

INTRODUCTION

The commune of Puchuncaví has historically been known for its fishing, agricultural and livestock activity, its slogan "where the land meets the sea" reflects its geographical condition and the historical relationship of its current 18,546 inhabitants (National Congress Library, 2017) with the territory. However, since the 1960s Puchuncaví has been involved in a context where its historical past as an agricultural, livestock, seaside and fishing zone fades due to the development of an industrial zone centrally managed by the State of Chile (Badal, 2014). The national productive project of Ventanas Industrial Complex (VIC) destroys local life in the name of development and economic growth aspirations (Shade, 2015, p. 2) (Figure 1). The historical component of environmental degradation has resulted in a constant growth of VIC and, consequently, of the externalities of its productive processes; main and most serious pollutants of the soil, water, air and land of the territory and of the precariousness of population's health (e.g. Salmani-Ghabeshi *et al.*, 2016; Poblete, Macari and Rodríguez, 2015; González, Muena, Cisternas and Neaman, 2008; Sánchez, Romieu, Ruiz, Pino and Gutiérrez, 1999). Due to the above is why the concept of Sacrifice Zone becomes important since, independent of its meanings, conceptually it allows to frame, imagine, identify and classify a place with the purpose of questioning perceived productive activities as destructive (Holifield and Day, 2017, p. 269).

Specifically, in that Puchuncavino context, a dystopian context with disparate national characteristics of socio-environmental precariousness, communities react through a "new eco-socio-environmental rationality founded on community and collective systems that seek to recover reciprocity and interdependencies in the relationships between nature and culture" (Bolados, 2016, p. 123). However, considering these elements as epistemologically divergent to the structuring of a Sacrifice Zone, it is relevant to ask an important question: What place do these visions have in the formal institutional context? To answer this question, this article first elaborates an introduction to the problem defined under the existence of the Sacrifice Zone. Then, the structuring elements of the current territorial planning are presented, and it is discussed how it promotes and perpetuates the existence of the Sacrifice Zone in Puchuncaví, based on a referential framework that supports the exploration of this study case based on theories about the coproduction of space.

Following Lefebvre (2013) and Augé (1993), the methodology used in the research presented here consisted of conducting a participatory and collective mapping workshop that sought to identify, recognize and characterize, on one hand, the personal experiences of the inhabitant of this area and, on the other, the impacts that industrial development has had on the territory. Finally, it was concluded that the Sacrifice Zone uses Territorial Planning Instruments (IPT, by its initials in Spanish) as institutional mechanisms for its development and perpetuation. The non-divergence of the productive project characterized as a Sacrifice Zone manages to be explained, in part, through the observation of the investigation that manage to frame a local territorial vision that does not find room for the institutional participation of the territory, which consequently promotes, due to the productive characteristics of the VIC, the territorial devastation seen as precariousness of the population and the ecosystem that sustains it.

Figure 1. Town of Las Ventanas, Commune of Puchuncaví, Quintero Bay. Source: Photograph of the authors.

SACRIFICE ZONE

The existence of the Sacrifice Zone of Puchuncaví does not constitute an isolated event. In Chile, it is possible to count five of them: Tocopilla, Mejillones, Huasco, Coronel and Quintero-Puchuncaví (National Institute of Human Rights, 2018). They house 27 of the 28 thermoelectric plants in the country - 20% of the installed energy capacity (CNE, 2019) - which generate 88% of the emissions of particulate material (PM), 91% NOx, nationwide among others (Chile Sustentable, 2018). In addition to thermoelectric plants, there are other industries that increase harmful emissions for these areas, evidencing the Chilean production model based on the exploitation of ecosystems and their resources (Terram, 2016). Among the productive sectors that are implanted in these areas, the main one is mining, followed by construction (cement), port, energy (fossil) and intensive farming. The consequent environmental and social degradation of industrial production causes a latent conflict, whose problem around Sacrifice Zones is transversal to the national productive model and, by extension, to the Chilean development model.

Understanding Sacrifice Zones as products of a specific development model, allows explore its structural components and, therefore, to make visible certain concrete elements that are capable of generating, perpetuating or promoting these areas in Chile. Investigations that have explored Sacrifice Zones from that perspective, contextualize them in Latin America in a particular territorial planning framework characterized as neoliberal territorial planning (e.g. Tellez, Name and Veríssimo, 2017; Bolados, 2016; Espinoza, 2015; Shade, 2015), that is, a planning designed from market liberation logics that seeks to accentuate massive processes of industrialization of capital based on a narrative of exploitation of the comparative advantages of the country (Piñera, 2018; Bachelet, 2014). Additionally, and from a global approach, Klein (2014) explains the origin of Sacrifice Zones, also characterizing them as a phenomenon influenced by the contemporary process of globalization of capital aligned and convergent with the formal planning instruments. In the case of Puchuncaví, this has specific socio-environmental implications, those that originate and visualize in the historical growth of the VIC regulated through Territorial Planning Instruments (IPT, by its initials in Spanish).

In that sense, in the Chilean context, understanding the production of Sacrifice Zones implies, among other things, studying the institutional elements that allow their existence, in other words, the elements of the Chilean neoliberal development model that have been shown to increase the level of environmental exploitation. These elements are articulated, according to literature, through public policies that encourage the investment of capital - national and international - in extractive sectors through (environmental) regulation and IPTs that prioritize income to production (Bolados, 2016; Carruthers, 2001; Altieri and Rojas, 1999). It is in the latter that this article seeks to focus its attention given its role as trigger vehicles of urbanization and globalization processes of the territory that are decisive for the industrial sector and, consequently, also determinants in the socio-environmental conflict of Puchuncaví as a Sacrifice Zone. Specifically, this article will explore the problem around IPTs as bridges for a specific vision of the territory that has managed to reproduce for 60 years the socio-environmental degradation in Puchuncaví.

On one hand, the State through territorial planning responds to the logic of the market, allowing the installation of companies and the environmental degradation of the territory where they are installed over the care for the ecosystem and the communities that inhabit it. The consequences of environmental impacts do not distinguish social classes, as Svampa and Viale mention, it is the vulnerable sectors of the population that suffer the most disproportionate environmental damage (2014, p. 83); impacts that, in the world of the economy, are considered as negative externalities

Figure 2. Territorial Planning Instruments Scheme. Author's elaboration based on IPT Scheme. Source: PRO-City Consultancy firm.

of companies. On the other hand, it is important to emphasize that the problem of environmental injustice related to Sacrifice Zones is an irrefutable fact and lies in the state of current Chilean environmental legislation (Infante, 2016), whose regulatory instruments applicable to different scales of the territory are still in a very incipient state regarding the inclusion of participation in decision-making, opposition and negotiation by vulnerable communities to influence current IPTs. Therefore, today these instruments favor the environmental devastation and the violation of the fundamental rights of inhabitants living in poverty and extreme poverty in vulnerable territories.

LAND USE PLANNING

The Territorial Planning Instruments (hereinafter IPT by its initials in Spanish) (Figure 2) have an order of hierarchy among themselves, which will define the range of action they may have in the territory where they are located. What defines the IPT are the zoning - in the case of major instruments, it will be "macro-zoning" - through which land use is defined and, therefore, what can or cannot be developed in place; whether they are industrial, residential projects, green areas, etc.

The IPT applied in the Commune of Puchuncaví are the following:

1. Valparaíso Metropolitan Regulatory Plan (PREMVAL)
2. North Shore Satellite Regulatory Plan (PRI-ZBSCN)
3. Puchuncaví Community Regulatory Plan (PRC)
4. General Ordinance of Urban Planning and Construction (OGUC)

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CO-PRODUCTION OF SPACE

Lefebvre (2013) states the concept of *space* has been defined from different areas of knowledge (geography, economics, demography, sociology, ecology, politics, commerce, etc.). In the field of urban planning and architecture, space is regulated through various planning policies and instruments established by the ordinance and laws (Infante, 2016), which, in turn, determines the construction of the spaces we inhabit.

Lefebvre defines three spaces related to who inhabits it: the mental space, referred to formal logics and abstractions; the *physical space*, practical, sensitive and the perception of nature; and the *social space* or the space of human interaction. The *social space* is produced on different scales by state social and political forces, it is multiple juxtaposing and interpenetrating. It is an abstract space of property and economic development, which relies on vast banking, commercial and industrial networks part of an economic and productive network that fragments work. This abstract space has been superimposed on the previously constructed space, space of those who have inhabited the territory, thus being forced to live under a system that develops projects in pursuit of a global economy, making invisible or eliminating the local economy.

One of the components of this economic network is the industrial estates, areas that for the purposes of this research have been categorized as non-places (Augé, 1993). In opposition to the *anthropological place*, *non-place* is defined as a space without identity, without relation and without history. The industrial estates are *non-places*, impersonal, not appropriate, where alteration is not possible because they are spaces of mere transit, where feelings of belonging and relationships with other subjects that are also passersby can hardly be generated. But the possibility of *non-place* is always present in any *place*, since both intertwine and interpenetrate.

The dissociations between multiple spaces that coexist in a *place* and *non-place*, in the case presented here, between the space of the industrial estate and the space of everyday life, can be analyzed through the *transduction* of Lefebvre, an intellectual operation that seeks understand reality by facts and its possibilities (Lefebvre, 2013, p. 97). *Transduction* is proposed from three types of space: the *space produced*, which corresponds to abstract constructions and imposed techniques; the *lived space*, subject to abstract constructions and symbols; and the *perceived space*, referred to daily practices and as a link between the two spaces mentioned above (Harvey, 1990). In this way, the subjective and imaginative dimensions would be incorporated into the urban and territorial analysis (Lindón, 2007). On the other hand, Gudynas proposes a social ecology and proposes "an articulation between different forms of knowledge, including sensitive or subjective experiences. The different perceptions and valuations of people about their environment can add to each other, appealing to interactive meeting and dialogue procedures" (Gudynas, 2004, p. 129) to define in a more concrete and Latin American way the abstract spaces of Lefebvre.

METHODOLOGY

METHOD

The study revealed that to understand inhabiting in relation to industrial development it is necessary to use a mixed methodology. To analyze the process and delimit the study to the urban and architectural area is why study variables are sought that, from a quantitative perspective are associated with specific data and, from a qualitative perspective, with information derived from the voices inhabiting the territory in study. From an integral logic, in the sense of assuming contextual reality as a complex, diverse and dynamic field of study, methodologies complement each other.

STUDY PER SCALES

The research aims to link the study of industrial development with communal development. Within this framework, the impacts on living are defined by systematizing the approach to reality on three scales: MACRO-Scale, MESO-Scale and MICRO-Scale, which respond to the three spaces proposed by Lefebvre in the theory of *transduction*. Each scale was associated, in turn, with a Research Instrument, the MACRO-Scale, with the bibliographic search in relation to Territorial Planning and Pollution (Community level linked to the space produced); the MESO-Scale with a designed activity called Collective Model/Mapping (Community level linked to the lived space); and the MICRO-Scale with individual questionnaires (Individual level linked to the perceived space). Specifically, for each scale we work with specific groups in terms of the number of people: for the MESO-scale we worked with two groups of 10 people with key informants among them, and for the MICRO-scale a questionnaire was applied to 83 people, for the socio-environmental diagnosis we worked with groups of 10 people from 4 different rural schools, among them, "La Quebrada". In this publication in particular the MESO-Scale will be presented in detail.

OBJECTIVE OF THE INSTRUMENT

The objective of Collective Model/Mapping is to build the sense of communal living from a collective perspective based on territorial recognition and communal economic development.

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Along these lines, a methodology consisting of a territorial recognition of anthropological sites was developed, followed by the description of communal development (past-present, productive activities) and, finally, the study of *non-place* (Augé, 1993). In relation to non-place, the Iconoclassist Collective Mapping Guide (Ares and Risler, 2013) was used, rescuing part of the proposed symbols for the activity and recognizing the impacts caused in the territory by industrial development.

The activity consists of three parts described below.

1. Territorial recognition

At the beginning of the workshop, a cartographic exercise was proposed consisting of each participant identifying and placing on a map of the territory their areas, spaces, routes, places, itineraries and all the places they like and also the places that cause distress and discomfort. The sum of them shows how each individual defines and characterizes the territory that will then be mapped collectively (Ares and Risler, 2013, p. 20).

[STEP 1] *Approach to the Model.* Locate their place of residence and a significant place in the commune (each participant).

[STEP 2] *Geographic Milestones.* Based on geographical milestones that Augé proposes the territory is characterized through the identification by the participants of the points linked to the following milestones:

2. Communal development

[STEP 3] *Productive Activities of PAST and* [STEP 4] *Productive Activities of PRESENT.* The second part is a comparison between what the commune was and what it is today, for which the participants are presented with productive activities previously identified, and the following files:

3. Non Place

[STEP 5] *Negative Impacts of Industrial Development.* It is proposed to study the impacts that industrial development has had and present the possible impacts that it has had on the commune. Impacts are identified with the following icons:

ANALYSIS METHODOLOGY

The *Collective Model* Instrument was analyzed quantitatively and qualitatively. The first analysis considered three steps: 1. Transcription of points and routes resulting from the activity from the model/base drawing to the communal drawing (maintaining the amount and position of the points indicated) (Figure 3). 2. Accounting of points (Figures 4 to 10) and compilation in tables to quantify what was obtained. 3. Determination of areas that involve the points indicated by layers.

On the other hand, the qualitative analysis considered the transcription and analysis of *Field Notes* based on the record made of the activity and classification of the participants' accounts, giving an account of their perceptions of living at the time of placing the proposed points. This activity was carried out in three categories: territorial recognition (anthropological place), communal development (productive activities) and industrial development (non-place). The following section includes literal transcripts of the most relevant stories expressed by the participants.

The activity described was applied in two different contexts; the first in the framework of the research

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that originated the design of the activity[1], in which the commune was analyzed through the communal model with two groups of 10 people each. In a second instance, it was applied to the Socio-Environmental Diagnosis of the local environment within the framework of the Certification Process for the Sustainable Schools Seal of the Commune of Puchuncaví, where places where the schools are located were analyzed[2].

Figure 3. Collective model register. Source: Photograph of the authors.

RESULTS AND DISCUSSION

The results obtained in both activities, according to the stages defined in the methodology, were compared with the objective of highlighting the repercussions on the perceptions of participants.

TERRITORIAL RECOGNITION

Based on Augé's (1993) theory of anthropological sites, participants identified their place of residence and significant places [STEP 1], making a first approximation to the model/mapping in order to locate geographical landmarks corresponding to the territory of analysis [STEP 2].

The answers obtained regarding territorial recognition were accompanied by explanations of the participants about the attachment and valuation of the territory, in which links from individual and collective memory were seen. The significant places identified were related to: the memory, the beauty of the place and the valuation of the flora and fauna existing in the commune. Next, quotes from the participants that reflect the aforementioned are cited: "Las Caletas, I come from a family of fishermen, and it is heritage that is forgotten", "Los Maquis Town for family history, upbringing and all life there"; "Las Ventanas, beautiful place to walk near the house".

Geographical milestones [STEP 2] identified allow us to account for a territorial assessment at the locality level, in which the quantity and variety of points located are highlighted, in addition to the essential aspects of living in relation to daily life and the collective imaginary . This makes it possible to recognize in the results urban design lines capable of evidencing potential productive possibilities of the local economy and, therefore, of an endogenous nature, linking them to urban planning that includes living and daily life as the basis of communal development.

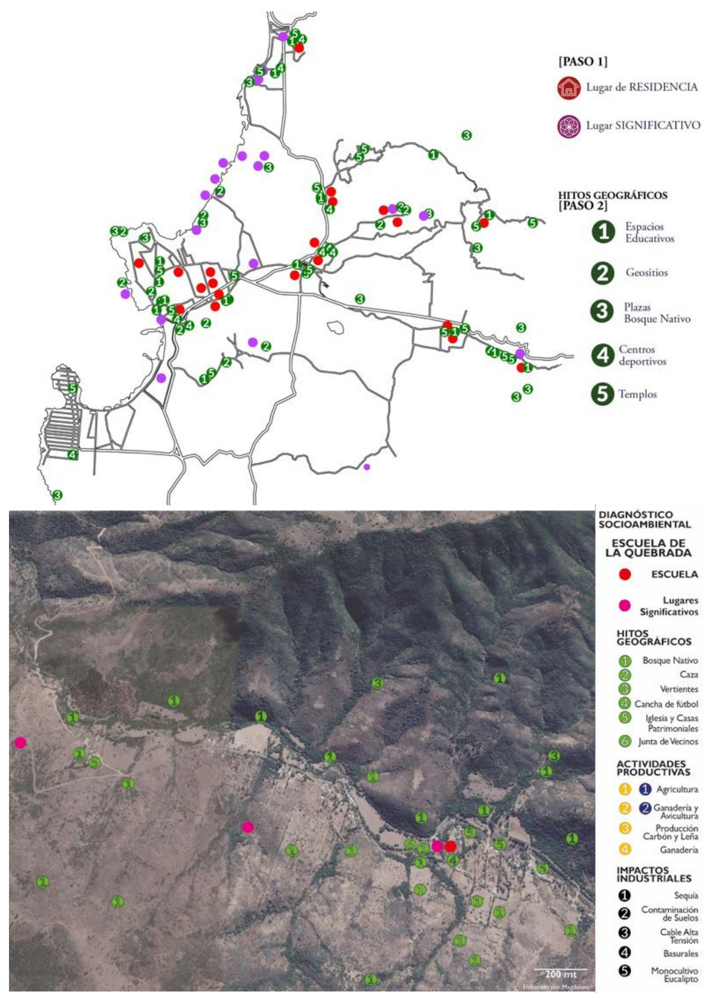

Figure 4 and 5. Steps 1/2. Collective Modeling - Commune of Puchuncaví. Source: Authors' elaboration.

[1] VERGARA; Magadlena, *Harm in the Commune of Puchuncaví: territorial crisis.* Undergraduate thesis, UTFSM, Valparaíso, 2019.

[2] This diagnosis was carried out in conjunction with the Poverty Overcoming Foundation, together with the NGO Puchuncaví Nativo and backed by the Illustrious Municipality of Puchuncaví, as a field activity carried out during the thesis process (idem).

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COMMUNAL DEVELOPMENT

[STEP 3] Identification of productive activities of the past.

Continuing the methodology with [STEP 3], participants described the past as a time of productive abundance, recognizing a common territorial identity, based on productive activities that created closeness and relationships between localities, linked territorially and geographically. These activities were part of the daily life of those who inhabited the territory due to practices related to them, i.e. threshing, drove of cattle. Thus, for example, it was reported: "Until 1971 it was produced in industrial quantities (bags of lentils, peas, beans and wheat); "Formerly in the afternoon animals were part of the routine, they returned to the houses so the roads were filled with them."

Comparatively, the development of VIC has been accelerated in relation to community development, with a different dynamic, which led to a deterioration of the environment in the commune. This has affected productive activities that connected the different localities, thus affecting the territorial identity at communal level (territorial fragmentation) and the inhabiting (daily life), which can be seen in the testimonies that follow: "With the installation of the first stack the released smoke was trapped in the valley and all locations were dying, it was filled with blue smoke"; "With the arrival of the industry, fishermen did not want to work in the industry because they earned more at sea, over time they ran out of resources"; "Until the 70's farmers could not grow more (Maitenes)".

[STEP 4] Present productive activities

Although both agriculture and livestock and fisheries declined significantly throughout the commune, today they are still practiced in smaller enclosures and close to localities, as noted in the following three accounts of the participants: "It is a mistake to say that agriculture is dead"; "Climate process added to the industrialization process has been a sum. There is no water to irrigate, even if there were no industries, there is no water for irrigation, so we could not have the same level of production that we had before"; "Last data from PRODESAL (cattle ranchers), 17,000 head of cattle (throughout the commune) were counted, before there was twice as much."

NON PLACE

When comparing productive activities of the present with the impacts of industrial development, we can see how they threaten what exists now, spread throughout the territory (Figures 6 and 7) covering the largest area of all locations. For this reason, some icons were not placed on the model, due to the generalization at

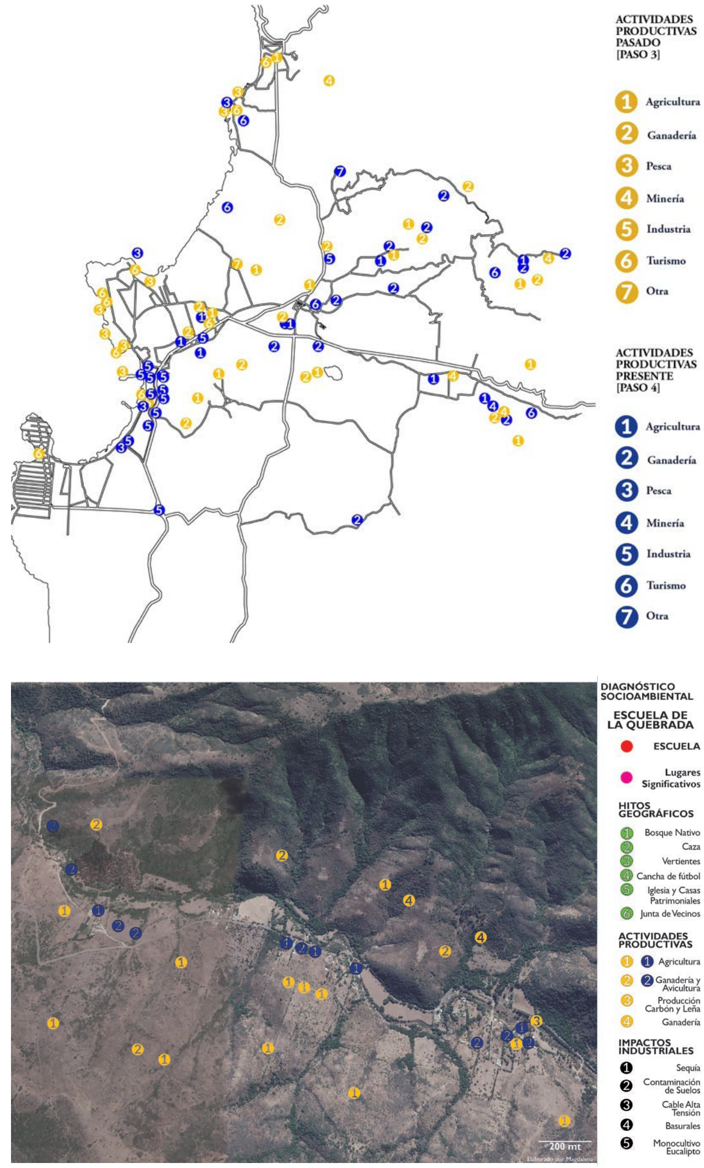

Figure 6 and 7. Steps 3 and 4. Productive activities of the past and present. Source: Authors' elaboration.

communal level of air pollution and drought, as one of the participants clearly states: "the entire model should be filled out because everything is contaminated, where you go in the commune there is pollution."

Agriculture and livestock, symbols of territorial union between localities, decrease significantly due to the negative externalities of industrial development, segregating the localities of the commune and reducing productive activities to populated centers. These impacts irreparably damage the environment, which affects the symbols and images that define the lived space and the territorial identity, consequently, the social space. The passively experienced space is defined by this absence of communal identity, as a result of the Sacrifice Zone, which in turn perpetuates a social-environmental crisis (Figures 8 and 9).

Habitar en una zona de sacrificio: Análisis multiescalar de la comuna de Puchuncaví
Sandro Maino Ansaldo, Nina Hormazabal Poblete, Magdalena Vergara Herrera, Matias Vergara Herrera
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Regarding community development, there is a lack of basic urban services, a basic need of the inhabitants that is not covered, which reveals where urban development points and the IPTs that privilege industrial development over integral communal urban development. This is precisely stated by another of the participants: "There is a problem in politics, instead of worrying about producing water for human consumption, there is concern for industries, so they are not compatible, water resource is clearly scarce."

CONCLUSIONS

The space is produced under certain canons that respond to a cultural and economic model of society. The national State has been consolidating worldwide, organizing and rationally planning society, imposing homogeneous measures, whatever the political ideologies, the historical past are or the social origin of the individuals in power have. The impact of these state decisions on a capitalist neoliberal system such as Chile has an impact on all scales: global-planetary, continental, national, regional, communal and individual.

IN RELATION TO TERRITORIAL PLANNING

Industrial development, based on IPT, has violated for decades the daily lives of those who inhabit the Sacrifice Zone, privileging the national/global economy over the local economy, through the indiscriminate growth of VIC and its consequent environmental and social damages. The commune of Puchuncaví is a sample of what happens at country level, with the different Sacrifice Zones, which are planned and perpetuated through the current IPTs, at the service of the centrally and hierarchically directed economic model, which ends forgetting the inhabitants of the place within the urban planning, leaving the entire local ecosystem subdued, damaged and sacrificed. In that sense, the collective model allowed to demonstrate through the characterization that participants (30 people in three activities) carried out, the position of the town in front of the VIC as a non-place, as an agent external to local issues that promotes an economy based on socio-environmental devastation.

IN RELATION TO TERRITORIAL IDENTITY

The impacts of industrial development on inhabiting and on the population are related to an accelerated deterioration of the territory in question, which has an impact on collective memory and, consequently, on territorial identity. The analysis instruments used prove that what VIC produces (or this type of development) is a territorial disorientation in the individual, due to the loss of territorial identity based on abundance, in the sense of constituting an image that is verbalized as "an abundant past" and a current "shortage". Those who participated denoted a territorial conscience, but the new identity imposed by the Sacrifice Zone suggests that everything is deteriorated so there is no

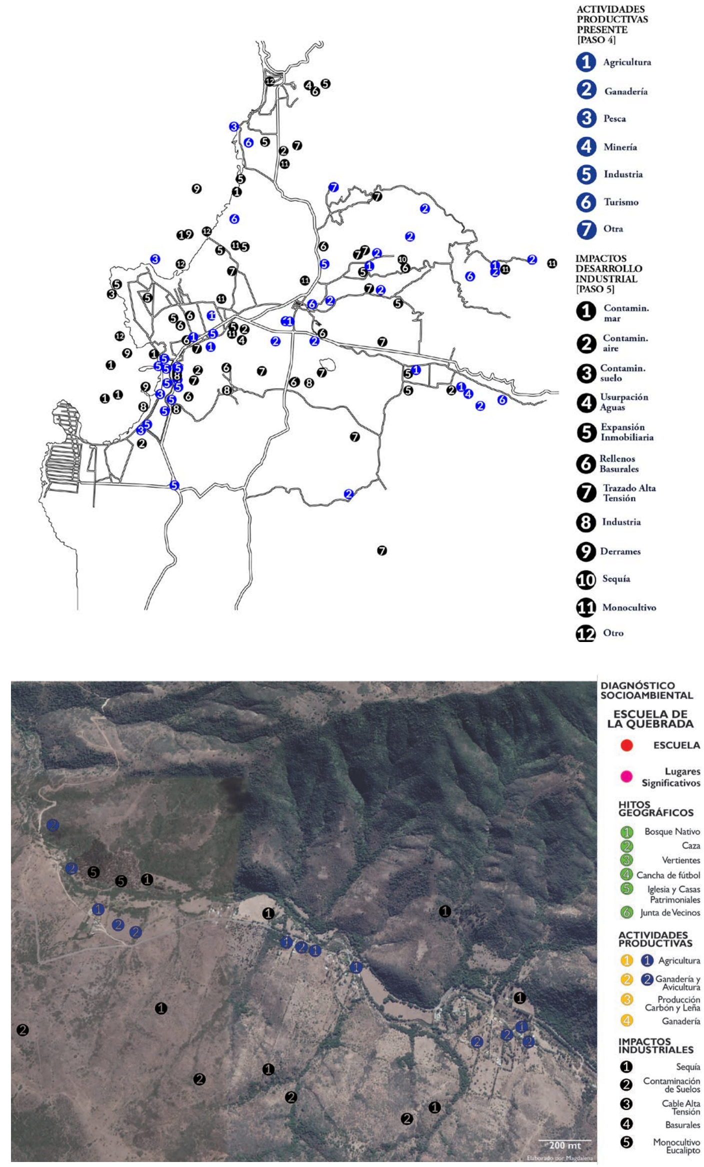

Figure 8 and 9. Step 5 and 6. Negative Impacts of non-place (black) with productive activities of present (blue). Source: Authors' elaboration.

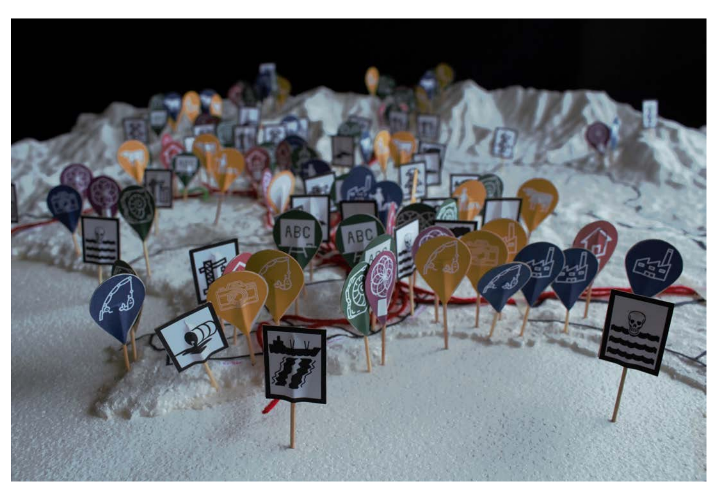

Figure 10. Image of the collective modeling. Source: Photograph of the authors.

knowledge of what still resists, as Augé states: "No longer a genesis but the decoding of what that we are in view of what we no longer are" (1993, p. 32). Non-place reveals the emergence of a new identity based on deterioration and pollution, leaving the Sacrifice Zone validated and, at the same time, resisted by collective consciousness.

IN RELATION TO TERRITORIAL RE-APPROPRIATION

Territorial appropriation implies a new rationality from the revaluation of the territory, which has been deteriorated, but still retains attributes described in the instruments. Collectively visualizing the current situation of the commune is of great importance for the transmission of knowledge about the commune and its localities to new generations, so that they can revalue the territory and raise awareness about these attributes that the commune has with a view to strengthen territorial identity, which entails the reconstruction of a territorial identity, therefore, a new territorial rationality. Identifying perceptions in the MACRO and MICRO scale can help establish a broader perspective on this issue, as well as identify forms of organization that allow articulating projects that develop a transition to more socially inclusive, environmentally more sustainable and economically more inclusive systems. Finally, coinciding with *social ecology*, it is more successful for our Latin American reality to set sail from the commitment to life, despite not fitting precisely with the method of scientific practice (Gudynas, 2004).

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URBAN OASIS: A THERMAL RETROFITTING PROPOSAL FOR THE SANTIAGO METRO

OASIS URBANO: UNA PROPUESTA DE ACONDICIONAMIENTO TÉRMICO PARA EL METRO DE SANTIAGO

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RESUMEN

Las estaciones subterráneas del Metro de Santiago pueden llegar a experimentar temperaturas de alrededor de 32°C en la zona de andenes durante la época estival, afectando directamente a los usuarios del transporte público. Situaciones similares se repiten en otros sistemas ferroviarios subterráneos del mundo y las soluciones implementadas no han logrado resolver el problema por completo, lo que se traduce incluso en altos costos de operación y mantención. Este trabajo expone una propuesta de acondicionamiento térmico pasivo que toma como caso de estudio la estación Tobalaba L1 del Metro de Santiago. Aprovechando los pozos de ventilación existentes, se simuló un sistema de enfriamiento evaporativo que busca reducir la temperatura al interior de la zona de andenes y, al mismo tiempo, contribuir a reactivar el espacio público en la superficie. La solución propuesta permitió una disminución de la temperatura promedio de 2,5°C en verano y 3,6°C en invierno, evidenciando que es posible llegar a igualar los alcances de algunas soluciones activas, pero con menores costos involucrados gracias al nulo gasto energético y al aprovechamiento de las preexistencias; y con mejoras en las condiciones del espacio público dada la incorporación del factor cualitativo aportado por la arquitectura.

Palabras clave
Climatización, estaciones de subterráneo, espacio público.

ABSTRACT

The underground stations of the Santiago Metro can experience temperatures of around 32°C in the platform area during the summer season, thereby directly affecting public transport users. Similar situations occur in other subway systems of the world and the solutions implemented have not been able to solve the problem entirely, even resulting in high operating and maintenance costs. This article presents a passive thermal retrofitting proposal that takes the Tobalaba L1 Santiago Metro station as its case study. Taking advantage of the existing ventilation shafts, an evaporative cooling system was simulated that seeks to reduce the temperature in the platform area and at the same time contribute to reviving the public space on the surface. The proposed solution made it possible to decrease the average temperature 2.5°C in the summer and 3.6°C in the winter. This demonstrates that it is possible to match the scope of some active solutions, but with lower costs associated with zero energy consumption and the use of existing elements, and with improvements in the conditions of public space by incorporating the qualitative factor from architecture.

Keywords
heating and cooling, subway stations, public space

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INTRODUCTION

HEAT IN METRO STATIONS

Year after year, in Santiago Metro there are repeated scenes of people fanning, shaking the shirt and, above all, sweating a lot, due to high temperature recorded inside stations, mainly underground, where temperature of around 32°C (Liencura, 2019) can be reached. Temperature-related environmental quality problems have a variable incidence throughout the year, but they are commonly associated to summer period (September to March).

Various journalistic sources link high temperature fundamentally to the central section of Metro line 1 (between Estación Central and Tobalaba), attributing this situation, on the one hand, to "... the greater influx of passengers caused by the implementation of Transantiago" ("Mega fans were installed", 2010) and, on the other, to "... the highest frequency of trains that travel in that section (main source of heat generation)" (Metro S.A., 2013).

For the study of internal thermal loads in the Metro, it is important to know the spatial and temporal situation of light bulbs, distinguishing differentiated regions, which are outlined in Figure 1. The areas of platforms and train circulation concentrate the greatest amount of internal loads, while access and mezzanine areas are considered to be outside the study because they contain less obvious loads.

Heat generated by the operation of trains constitutes, by far, the main existing load (92%), mainly due to the braking system that occupies about half of the total internal thermal load. Then the facilities follow with (6%) and in smaller quantity the occupants (2%) (Figure 2).

Exposure to very hot environments can lead to a series of consequences, which affect passengers and Metro staff alike. Here you can distinguish both annoyance and discomfort, as well as health conditions, in the most serious cases. In addition, this also results in social exclusion of those people who may be more vulnerable to the effects

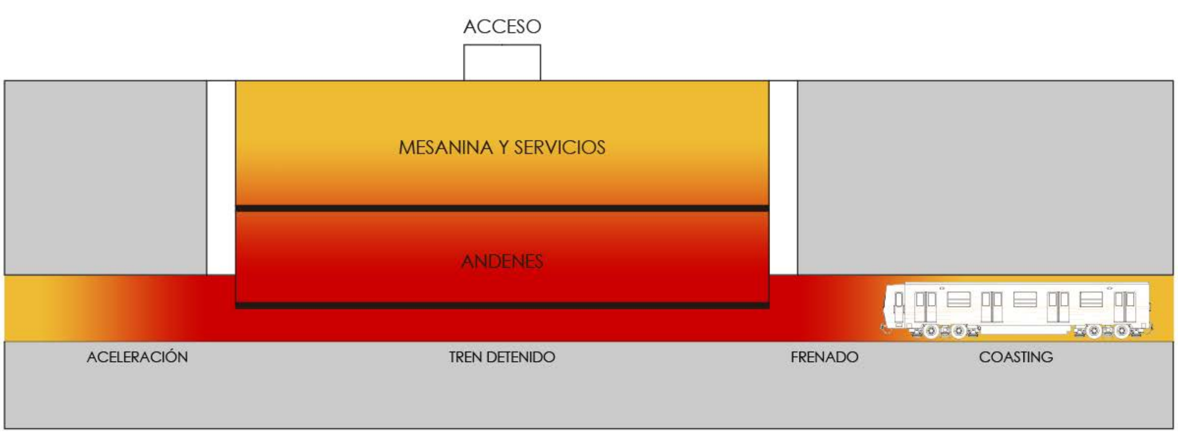

Figura 1. Scheme of internal thermal loads. Source: Made by the author.

Fuente	Carga térmica	Leyenda
Funcionamiento de los trenes	Frenado	
	Tracción	
	Fenómenos aerodinámicos	
	Contacto rueda-riel	
	Climatización de trenes	
Instalaciones	Alumbrado y distribución eléctrica	
	Equipamientos	
	Locales comerciales	
	Climatización de salas técnicas	
Ocupantes	Calor sensible	
	Calor latente	

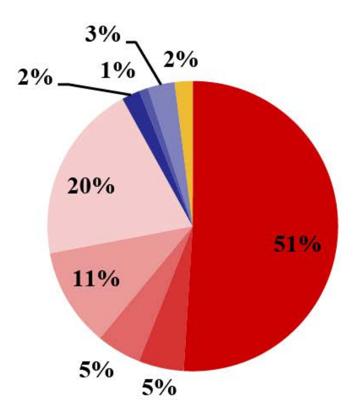

Figura 2. Distribution and classification of internal thermal loads. Source: Made by the author based on Herrero (2009).

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due to their specific condition (infants, elderly people, pregnant women, etc.).

MEASURES ADOPTED TO FACE THE PROBLEM

PASSIVE VENTILATION SYSTEM

In underground stations, where the problem is more critical, the heat generated must be evacuated to the outside of the system. The main sumps are, in this sense, the atmosphere and, to a lesser extent, the surrounding terrain. That is why ventilation has become the main cooling alternative, constituting a system that operates through the following components:

Extraction wells: They are located in the vicinity of the midpoint of sections of the inter-station tunnel and their function is to extract hot air from inside (Figure 3).

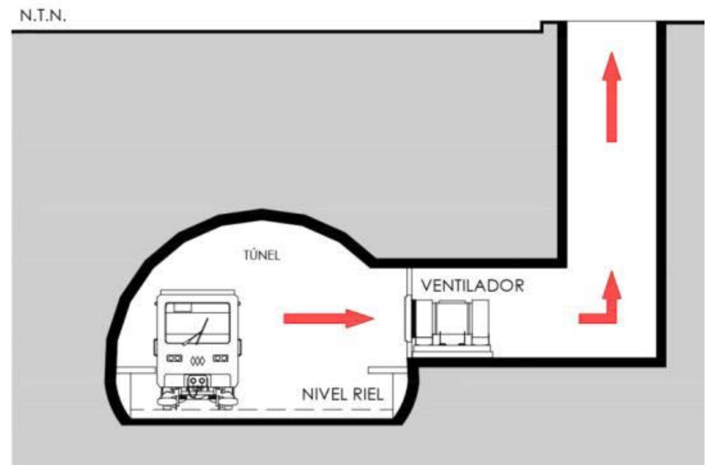
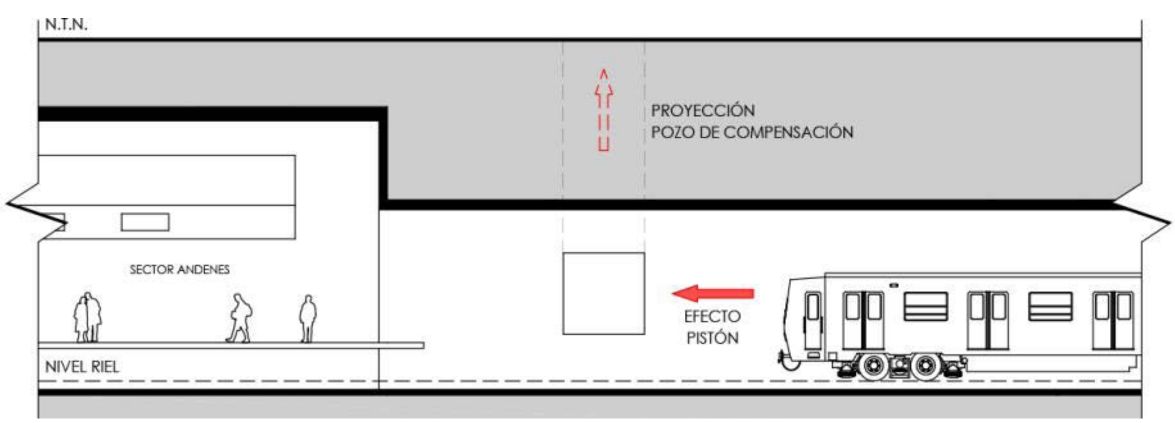


Figura 3. Cross section of extraction wells. Source: Made by the author based on Herrero (2009).

Compensation wells: They are located in the input and output sprockets of each station. Its function is to avoid the discomfort of air generated by the piston effect, a phenomenon that occurs when the train traveling through the tunnel, pushes the air that is in its path so that before this, a layer of air is generated with pressure higher than normal (Figure 4).

Immission wells: They are located on the platform and through them air is propelled from the outside with the help of fans in order to increase air renewal. Generally, immission wells are omitted (with few exceptions), when, instead, the entry of air from the outside is associated to compensation wells in periods where the piston effect does not occur (Figure 5).



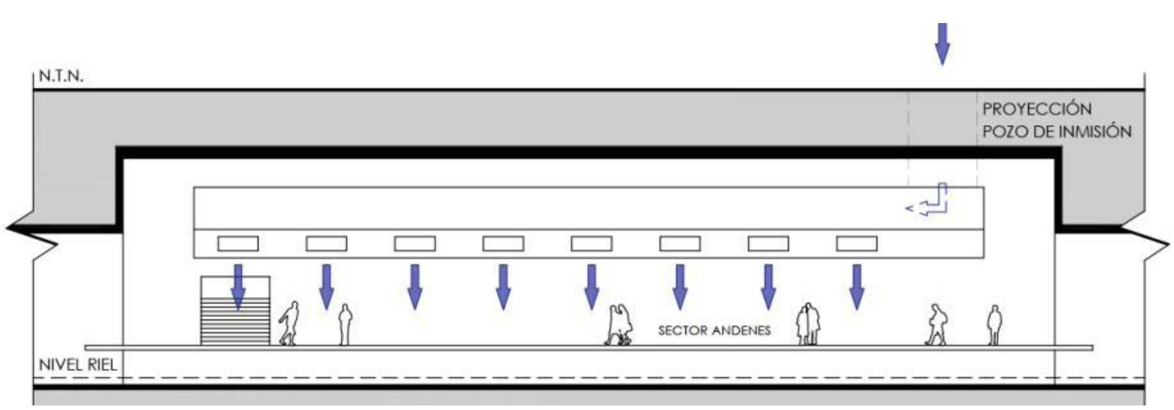


Figura 4. Longitudinal view of compensation wells. Source: Made by the author based on Herrero (2009).
Figura 5. Longitudinal view of immission wells. Source: Made by the autorbased on Herrero (2009).

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ACTIVE VENTILATION SYSTEM

As a way to complement passive ventilation systems, which do not solve the central problem, Metro company has implemented summer plans that include the incorporation of air-conditioned trains and active ventilation systems in stations, with investment costs that only up to 2010 exceeded $ 2,000,000,000 (Metro S.A., 2010). Specifically, at present, the recent summer plan 2018-2019 considered the installation of 106 mega-fans in 8 different stations, the installation of doors with ventilation grilles on cars of lines 2 and 5, and the provision of air conditioning for the complete fleet of lines 1 and 6 ("With 106 fans", 2018).

Figure 6 shows the installed park of active ventilation systems to the year 2015 in Metro stations, where the following are noticed:

Nebulizer fans: Ventilation equipment using a high pressure electric pump and special nozzles to cool the air temperature using water mist.

Conventional fans: Ventilation equipment that increases the movement of air masses inside.

Mega fans: Industrial ventilation systems that take advantage of the piston effect to induce the movement of hot air masses through it by generating an additional air flow. They operate by means of lattices and/or fans that can be both injection and extraction, depending on the need.

Tunnel fans: Industrial ventilation systems installed in the extraction wells, which aim to strengthen indoor air intake.

SOLUTIONS IMPLEMENTED IN OTHER COUNTRIES

SÉ STATION, SÃO PAULO METRO, BRAZIL

In Sé station of São Paulo Metro, passive conditioning strategies were implemented where large openings were located towards Praça da Sé, a large open public space that incorporated vegetation and water mirrors. The strategy sought to implement the evaporative cooling technique, whereby the air entering the station lowered its temperature due to the effect of water provided by the environment. However, due to São Paulo weather, characterized by the high presence of relative humidity, evaporative cooling proved not to be feasible, since it requires a particularly dry climate (Figure 7).

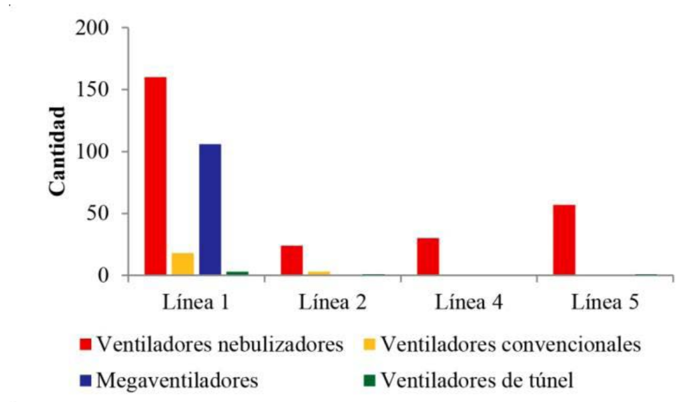

Figura 6. Active ventilation equipment park per line. Source: Made by the author based on Metro S.A. (2015).

Figura 7. Link between Praça da Sé and Sé Station. Source: Author photo

PACIFIC STATION, MADRID METRO, SPAIN

A geothermal system based on the use of subsoil temperature as an air conditioning system was incorporated in the Pacific station of Madrid Metro. In this, a geothermal heat pump mechanism is used employing the subsoil, in winter as a heat source, and, in summer as a heat sink, in order to maintain stable temperature levels throughout the year. This pump is connected to the subsoil through a terrestrial heat exchanger that allows conduct the thermal load (Figure 8).

NORTHERN LINE, LONDON UNDERGROUND, UNITED KINGDOM

In the Northern Line of London Underground, and taking into account the oceanic climate of the city, the heat generated by the system is used to heat homes by incorporating air capture tubes that divert heat to the heating network of the power plant of Bunhill Council, which in turn connects with hundreds of homes that can make use of thermal energy through radiators (Figure 9).

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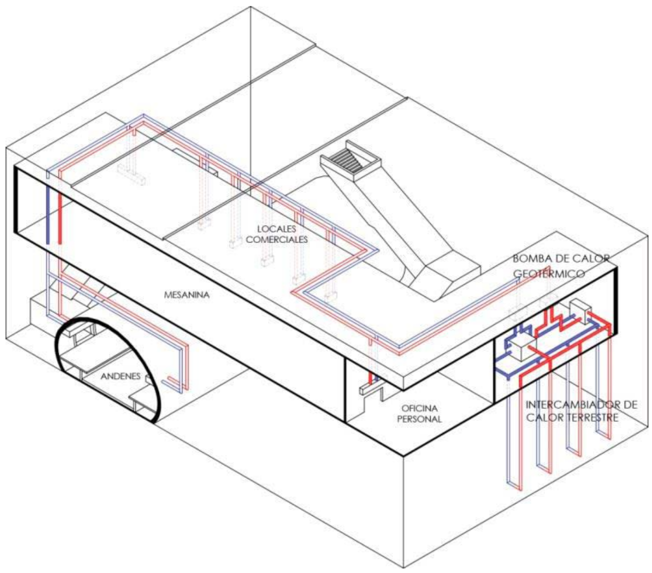

Figura 8. Operation of the geothermal system. Source: Made by the author based on Hendriks, Cubillo and Cuesta (2011).

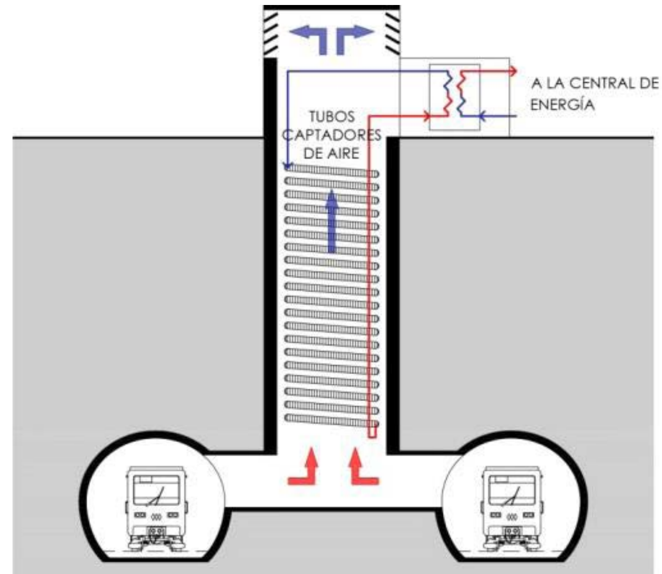

Figura 9. Operation of the heating system in the Northern Line. Source: Made by the author based on Arden (2013).

METHODOLOGY

For the study and diagnosis, it was decided to work based on the key variables of the problem: ambient temperature, ventilation and air humidity. Solar radiation goes to the background, since in underground stations - considered the most critical typology in this context - the problem is fundamentally linked to internal thermal loads.

In order to respond to the problem, a case study was determined in which an intervention proposal was developed, having as conditions the use of pre-existing and the incorporation of passive conditioning strategies to achieve a replicable and low-cost design. The proposed alternative was subjected to evaluation and analysis based on what exists to validate the working hypothesis.

FIELD MEASUREMENTS

It was sought to determine the temperature and humidity levels inside the station, through biweekly records (working day and weekend) for 2 weeks each month, between the months of October and March. The measurements were carried out at peak morning hours, valley hours and late afternoon hours, to then average the results.

An EXTECH model 44550 environmental thermometer was used, considering an acclimatization period of 5 minutes for taking results.

Outdoor weather data were obtained from Norwegian Meteorological Institute data (The Norwegian Meteorological Institute, 2016), extrapolated to the location of the station under study, according to its coordinates.

Type	Parameter	Time table			
		Low	Morning peak	Valley	Evening peak
Activity	Occupation (people/m^2)[1]	1,8	5,9	2,9	5,3
	Metabolic rate (W/people)[2]	Standing relaxed = 1,2			
	Metabolic factor	0,9			
	Clothing (clo)	Winter = 1,0 / Summer = 0,5			
	Thermal load by devices and equipment (W/m^2)	225	750	375	675
Enclosures	Heavy work structure	Reinforced concrete			
Lighting	Type of luminaire	Fluorescent equipment T8			

[1] Metro S.A., 2007.

[2] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2017.

Table 1. Parameters for energy simulation of the model. Source: Made by the author based on the indicated sources.

ENERGY SIMULATION

Energy simulations of the model were carried out with DesignBuilder software according to parameters summarized in Table 1.

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According to the studied background, the following analysis instances were defined:

6:00 A.M., August 1: Low working hours, with the lowest temperature record of the year (winter situation).

6:00 P.M., December 20: Evening peak time on business day, with the highest temperature record of the year (summer situation).

To determine the scale of thermal sensation, the Fanger method was used (Fanger, 1973): a tool for the assessment of thermal comfort in indoor spaces, which contemplates various variables present in the person-environment thermal exchanges and quantifies the values through an average valuation index called the estimated average vote (PMV, by its initials in Spanish) and the estimated percentage of dissatisfied people (PPD, by its initials in Spanish) (Figure 10).

The results obtained by the software were introduced in the CBE Thermal Comfort Tool (Hoyt et al., 2017), which is based on UNE-EN 15251 Standard that establishes a classification of results according to different categories (Table 2).

PMV	PPD	Sensación
3	99 %	Muy caluroso
2	77 %	Caluroso
1	26 %	Ligeramente caluroso
0	5 %	Confort (neutro)
-1	26 %	Ligeramente frío
-2	77 %	Frío
-3	99 %	Muy frío

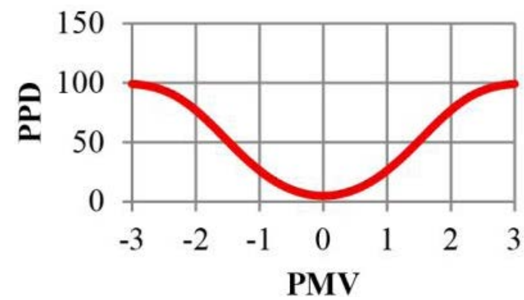

Figura 10. Thermal sensation scale according to Fanger method. Source: Made by the author based on Arballo Kuchen, Alamino-Naranjo and Alonso-Frank (2016).

Category	PPD	PMV	Description
I	< 6 %	-0,2 a +0,2	High level of expectation. Recommended for spaces occupied by people with weakened and/or sensitive defenses with special requirements.
II	< 10 %	-0,5 a +0,5	Normal level of expectation. It should be used for new and renovated buildings.
III	< 15 %	-0,7 a +0,7	Acceptable and moderate level of expectation. It can be used in existing buildings.
IV	> 15 %	<-0,7 ó >+0,7	Values outside the criteria of previous categories. This category should only be accepted for a limited period of the year.

Table 2. Categorization by thermal expectation levels according to standard UNE-EN 15251. Source: AENOR, 2008.

EVALUATION COST/BENEFIT

In order to determine comparative advantages of the proposal, they were evaluated in relation to the main active ventilation systems used in Santiago Metro (mega fans and nebulizer fans), from the following points:

1. Investment costs.
2. Operation costs.
3. Maintenance costs.
4. Extent of reach and units per station.
5. Operation and effectiveness in temperature reduction.

RESULTS AND DISCUSSION

IDENTIFICATION OF THE STUDY CASE

As a study case, it was determined to work with Tobalaba station, as it gathers the greatest number of constraints determining the problem:

Location: It is positioned in the most critical section of line 1, being the station with the largest influx in the network, as it contemplates an estimated 83,593 passengers per day on business days (Herrera, 2018).

Typology: It corresponds to an underground station, so that higher heat concentrations can be experienced as there is a difficulty in ventilation from the outside. In addition, it is a point of combination between lines 1 and 4, so it affects a greater influx of passengers by supplying routes in more ways and allows studying possible temperature differences between platforms of both lines.

Energy expenditure: Tobalaba station has the largest amount of active ventilation equipment in the network, among which the majority corresponds to nebulizer fans (Metro S.A., 2015).

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INTERVENTION PROPOSAL

The proposal is developed from the surface level through the intervention of existing compensation wells to generate an evaporative cooling system. This, incorporating the concept of "Urban Oasis", through which, in analogy to an oasis in the desert, the initiative seeks to contrast with the built environment and generate a microclimate that becomes the prelude to the entry of air into the station, which, once conditioned, will be introduced by incorporating wind towers that will be linked to the interior. At the same time, it helps to reactivate the areas on compensation wells by generating spaces for social interaction.

For purposes of the study of the proposal and optimization of time, it was determined to develop a single intervention in the western compensation well on line 1 (Figures 11 and 12).

Figura 11. View of the proposal from south sidewalk. Source: Made by the author.

VALIDATION OF THE PROPOSAL

FIELD MEASUREMENTS

As shown in Figure 13, line 1 of Tobalaba station concentrates the highest temperatures, while towards line 4, despite experiencing differences of only 2.0°C with respect to the previous one, the problem is only evident at the most critical moments. This may be due to the lower circulation of trains to the substation of line 4 because it is terminal, with the understanding that the operation of trains represents the highest percentage of internal thermal loads. On the other hand, the location of line 4 at greater depth can generate a tendency towards thermal stability, especially considering its location under San Carlos channel, which has a lower radiant temperature.

The differences of the station with respect to the outside can reach 7.9°C on average, reaching maximums close to 33°C, which is explained by the zero incidence of solar radiation inside and by the presence of high internal thermal loads, mainly based on the influx of passengers and the frequency of trains (higher during peak hours and business days). Meanwhile, the relative humidity inside reaches very low levels, around 40%, which is due mostly to temperature, in an inversely proportional sense, and evidences the dryness of the air.

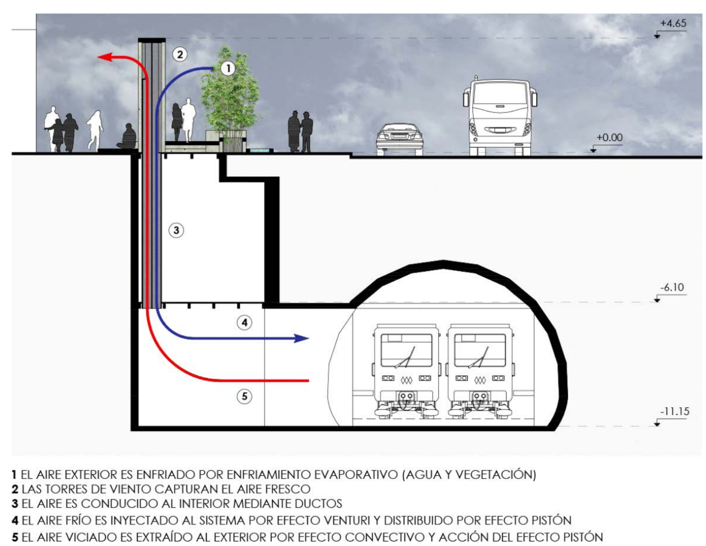

Figura 12. Cross-section of proposed A-A'. Source: Made by the author.

ENERGY SIMULATION

Weather

Due to the wide thermal oscillation that Santiago experiences, great climatic differences are perceived in winter and summer. In December 20th, the recorded temperature is high, reaching the maximum during the

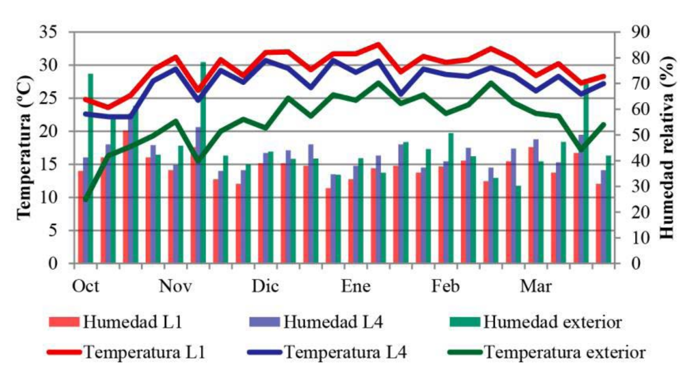

Figura 13. Temperature and humidity records in Tobalaba station. Source: Made by the author.

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Parameter	Winter	Summer
	August 1st	December 20th
	6:00	18:00
Dry bulb temperature	-5,8°C	32,0°C
Wet bulb temperature	-5,8°C	18,3°C
Relative humidity	100%	26%
Wind speed	0,0m/s	4,1m/s
Direction of the wind		South-North

Table 3. Average weather parameters for Santiago. Source: Made by the author.

Parameter	Winter		Summer		Optimal range
	August 1st		December 20th		
	6:00		18:00		UNE-EN ISO 7730
	Current	Proposed	Current	Proposed	
Air temperature	28,2°C	24,6°C	34,3°C	31,8°C	10 to 30°C
Relative humidity	45%	45%	35%	50%	30 to 70 %
Air speed	0,0m/s	0,1m/s	0,0 m/s	0,1 m/s	<1 m/s

Table 4. Results of the energy simulation. Source: Made by the author based on AENOR, 2006.

year, which translates into low relative humidity. In August 1st, however, the situation is the opposite, registering the lowest temperature of the year, with a relative humidity of 100%, which implies that water steam that no longer admits air condenses as dew. Wind behavior also varies in both situations, but in general the speed is not considerable, which could harm the strategies contemplated in the proposal (Table 3).

Station

The concentration of high temperatures on platform occurs, particularly in December 20th, when the air temperature reaches the most critical parameter (Table 4). This is a direct consequence of internal thermal loads inside the station, which are also stressed by the zero air velocity apart from the air produced by convective effects. In general terms, the proposal does not change this situation to a greater extent, but it does begin to show the entry of air from the ventilation well, being able to increase and reach more acceptable values with the increase in circulation at the exit point (Figures 14 and 15).

It is worth mentioning, however, that the air movement associated with active ventilation systems and the air flow induced by the piston effect of trains, which can reach values close to 1.8m/s in very determined areas and moments are not considered (Herrero, 2009, p. 79).

Regarding air temperature, the implementation of the proposal achieves an average reduction of 3.6°C in winter

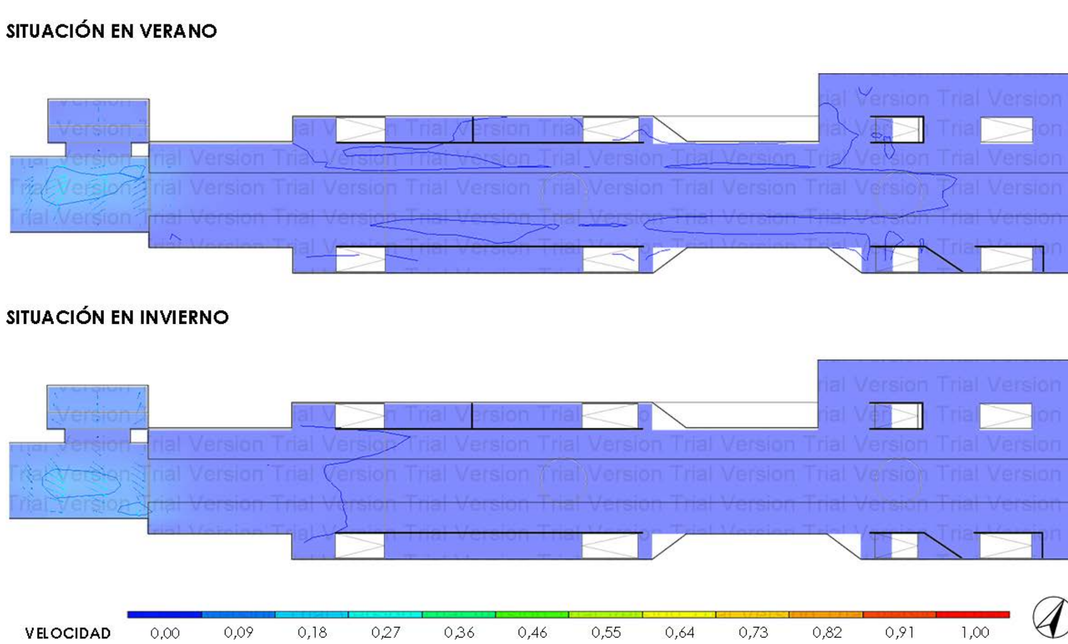

Figura 14. Air speed for the existing situation. Source: Made by the author.

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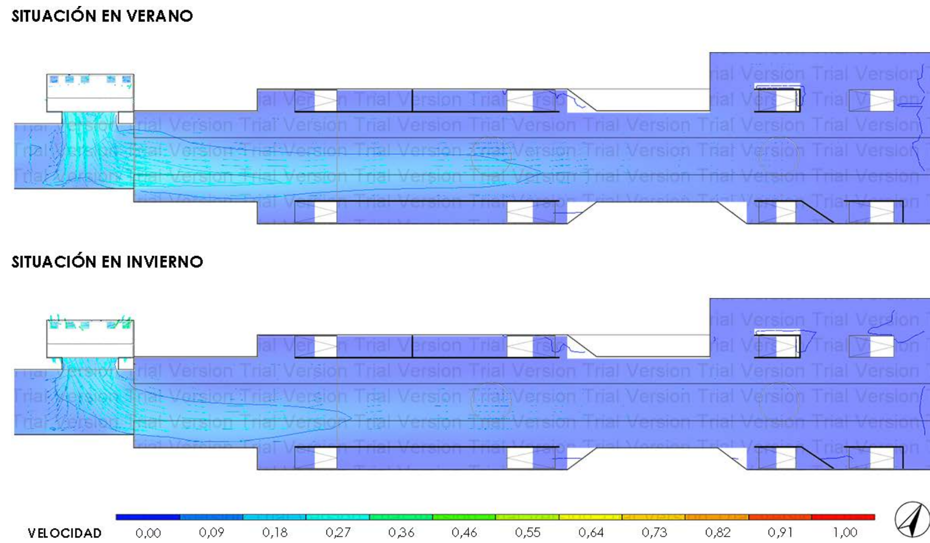

Figura 15. Air speed for the existing situation. Source: Made by the author.

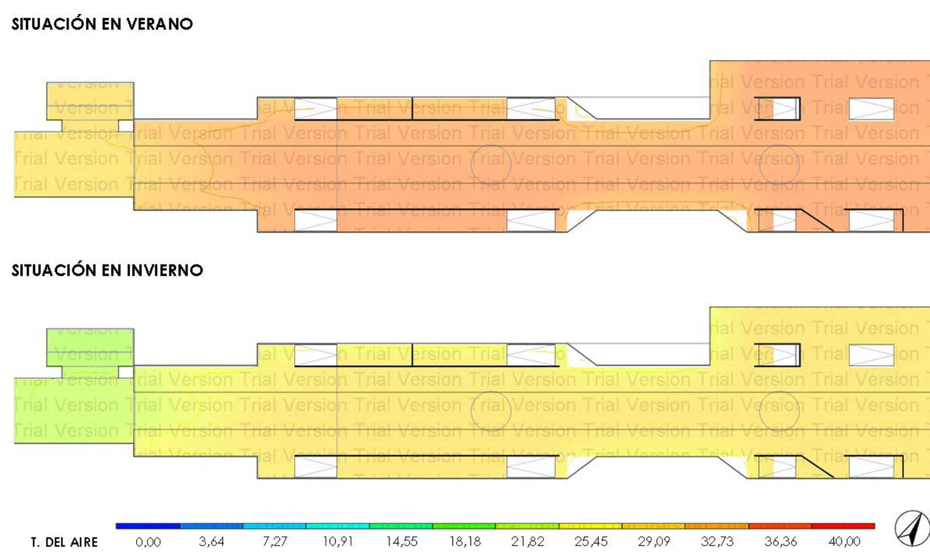

Figura 16. Air temperature for the existing situation. Source: Made by the author.

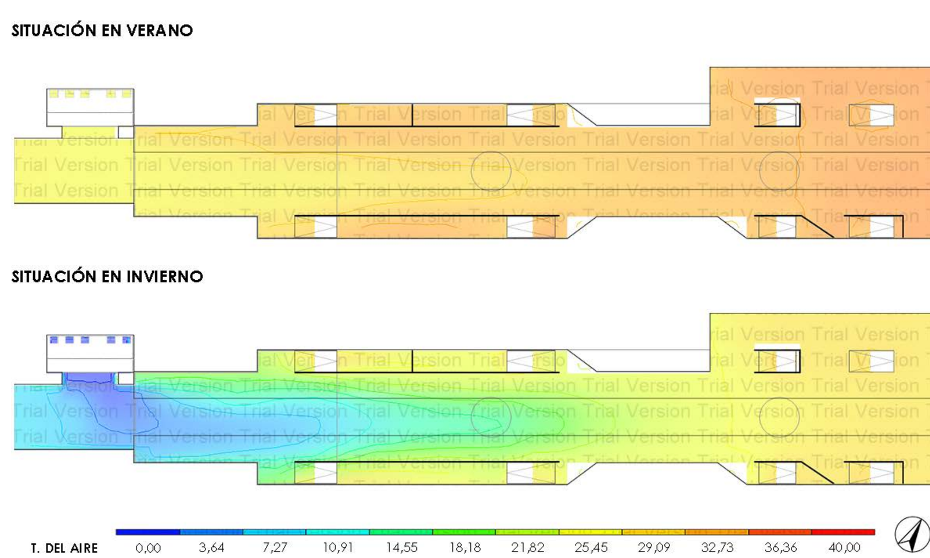

Figura 17.Air temperature for the proposal. Source: Made by the author.

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Index	Winter		Summer		Optimal range	
	August 1st		December 20th			
	6:00		18:00			
	Current	Proposed	Current	Proposed	UNE-EN ISO 77301	UNE-EN ISO 152512
PMV	1,36	0,81	2,65	2,35	-2,0 a +2,0	-0,7 a +0,7
PPD	44%	19%	96%	90%	<77 %	<15 %
Category	IV	IV	IV	IV		I a III

Tabla 5. Thermal sensation indicators. Source: Made by the author based on the indicated sources

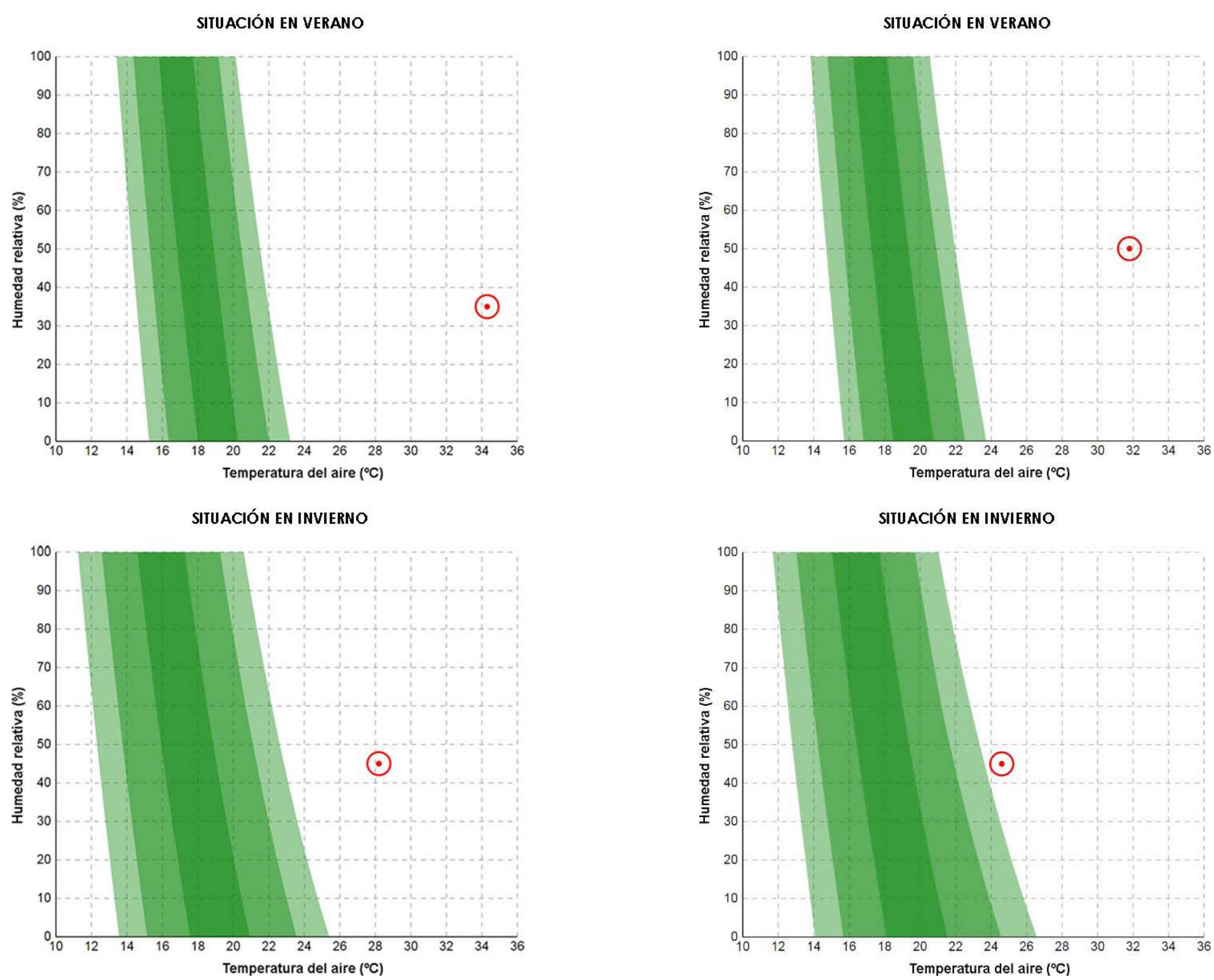

Figura 18. Hygrothermal comfort of the existing situation according to standard UNE-EN 15251. Source: Made by the author based on Hoyt et al., 2017.
Figura 19. Hygrothermal comfort of the proposal according to UNE-EN 15251. Source: made by the author based on Hoyt et al., 2017.

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and 2.5°C in summer. These values are even more favorable than those obtained from field measurements for the substation of line 4 where, despite the small difference, a considerable change is already perceived.

The relative humidity inside is low for both situations, which guarantees the proper functioning of the evaporative cooling system, which also helps to stabilize these values due to the evaporation of water and humidification of air.

Temperature problems are accentuated, in general, as distance is greater from the existing compensation well, which shows that, for both situations, the temperature produced by internal thermal loads is higher than the outside temperature (Figures 16 and 17).

When determining the scale of thermal sensation by Fanger method (Table 5), values are obtained that represent a very hot (PMV ≈ 3) and hot (PMV ≈ 2) environment in summer and a slightly hot environment (PMV ≈ 1) in winter. Although in practice during winter it could be pleasant to stay on the platform, the Fanger method considers clothing, with the aim of determining a comfort such that it is not necessary to vary the garments to adapt to a certain environment.

The proposal, although maintaining similar values, manages to reduce the estimated percentage of unsatisfied people in the platform area by 6%, in December 20th, and by 25%, in August 1st, thus being classified in category IV that it is acceptable only for the most critical periods.

If these values conform to UNE-EN ISO 7730 standard, in neither case would this be fulfilled by December 20th, while in August 1st the situation would be favorable. However, UNE-EN 15251 standard, being more precise, determines values outside comfort for both situations, although the critical scenario is in summer anyway.

Figures 18 and 19 allow determine the relative humidity and air temperature values that would be required under the rest of the conditions registered according to UNE-EN 15251 standard, being able to conclude that, despite temperature reductions obtained with the intervention, comfort for both situations remains unfulfilled. This makes it necessary to reduce the air temperature by around 10°C, considering a relative humidity between 30 and 50% for the most unfavorable situation in summer.

ASSESSMENT OF THE PROPOSAL VIABILITY

COST

As shown in Table 6, referring to investment costs, the proposal represents the highest investment per unit, but since only two are required at the station, the total investment is lower than that considered by nebulizer fans, but not by mega fans. The above is explained by the quantity of materials and labor required for the proposal, which, added to longer construction times with respect to other alternatives, may be the least profitable option at this point.

		Mega fans	Nebulizer fans	Proposal
Units per station		2	28	2
Unit cost	Invesment (M$)	12.000,0 a 15.000,0 [1]	1700,0 a 2000,0 [1]	18906,1
	Operation (M$)[3]	210	70	
	Maintenance (M$)	10.074,5	10.074,5	98,1 [5]
Total cost	Investment (M$)	24.000,0 a 30.000,0 [1]	47600,0 a 96.000,0 [1]	37.812,2
	Operation (M$)[3]	420	1.960,00	
	Maintenance (M$)	10.074,5	10.074,5	196,2 [5]

[1] Metro S.A., 2013.

[2] Estimated value according to the estimated budget of the works based on Ondac, 2018.

[3] Estimated value considering an operating period of 7 months (summer period).

[4] Estimated value based on estimated maintenance costs for active ventilation based on the National Statistics Institute, 2019.

[5] Estimated value based on the cost per m2 of green area for the commune of Providencia (Guzmán, 2017)

* M$= Thousands of Chilean pesos.

Tabla 6. Unit and total costs for analyzed alternatives. Source: Made by the author based on the indicated sources

However, in relation to operation and maintenance costs involved, it is evident that the proposal is the most convenient option, far from the other alternatives. This is one of the main characteristics of passive conditioning systems, which do not require specialized personnel for maintenance or consider expenses for the use of electricity. In the long term, these conditions determine the profitability of the proposal, which is estimated to be profitable between the first and second year of operation, with respect to mega fans.

BENEFIT

Once the attributes associated to each alternative have been compared (Table 7), it is estimated that, although the proposal alone achieves a smaller contribution in terms of temperature reduction, its values could be equal to the operation of mega fans if 2 units are considered by season, the situation may be more favorable or not depending on the area in which it is determined.

Nebulizer fans lead in terms of temperature reduction, but their extent is very limited compared to other alternatives. Even so, the modes of operation of each alternative allow determine that these could be complementary.

Despite the above, the initiative associates other benefits linked to the contribution of public space on the surface that can favor the effectiveness of the investment.

System	Units per station	Scope	Temperature reduction (°C)	Operation
Mega fans	2	Platform	3 to 5 in peak time	Piston effect
Nebulizer fans	28	Up to 2 meters on platform	6 per unit	Nebulized water
Proposal	2	Platform	About 3 per unit	Fresh air intake

Tabla 7. Efficacy of the analyzed alternatives. Source: Made by the author based on Metro S.A., 2010.

CONCLUSION

The problem of high temperatures inside underground railway stations, although often it turns out not to be a priority issue to address, leads from health conditions to social exclusion, in the most critical periods, and not only occurs in the Metro of Santiago, but also in underground railway systems around the world, independent from weather conditions. This is due to the fact that the problem is linked to the presence of high internal thermal loads, mainly due to the operation of trains, which may result in temperatures up to 34°C in summer for the platform area.

The measures that have been taken in Santiago Metro include the use of active ventilation systems that, in addition to contemplating high energy expenditure, have not achieved completely effective results, which leads to the implementation of new plans year after year. In other places of the world the situation is similar, highlighting solutions based on mixed conditioning systems (passive and active), but which may not be viable in countries that have more limited resources or when other priorities are in mind. Therefore, architecture has much to contribute from the introduction of passive conditioning strategies and qualitative factors that prioritize the user.

The “Urban Oasis” proposal, although it does not fully solve the problem, contributes by demonstrating that it is possible to match and/or complement the scope of active systems by implementing passive conditioning systems, having the advantage of greatly reducing costs of maintenance and operation due to zero energy expenditure, and being able to reduce investment costs when preexistence is used. At this point, the use of existing compensation wells gives the proposal a double functionality, allowing to contribute to the public space on the surface through spaces based on versatility and spatial ambiguity.

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AN EVALUATION OF THE IMPROVEMENT OF THERMAL COMFORT WITH THE INCORPORATION OF SUSTAINABLE MATERIALS IN SELF-BUILD DWELLINGS IN BOSA, BOGOTA, COLUMBIA.

EVALUACIÓN DEL MEJORAMIENTO DEL CONFORT TÉRMICO CON LA INCORPORACIÓN DE MATERIALES SOSTENIBLES EN VIVIENDAS EN AUTOCONSTRUCCIÓN EN BOSA, BOGOTÁ

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RESUMEN

En este artículo se evalúa cómo la incorporación de materiales sostenibles mejoró el confort térmico en un hábitat en proceso de autoconstrucción, en el barrio San José de Bosa, en Bogotá, Colombia. El problema del confort se ha abordado como una condición fundamental del hábitat que responde a una necesidad de cobijo, de tener un espacio propio, sin importar la forma en que este espacio responda a las variables climáticas. Por otra parte, el uso de materiales sostenibles ha ido incorporando beneficios ambientales, en especial en las grandes ciudades, debido a los altos índices de contaminación actuales. En los barrios periféricos, como el aquí abordado, el cemento, el ladrillo y el acero son los materiales más usados en la construcción. Concretamente, se expone en lo que sigue un estudio de caso en el que se hicieron mediciones periódicas con el objetivo de determinar el balance térmico y el modo en que los materiales empleados respondían a las condiciones climáticas existentes. Con el fin de optimizar no solo el confort térmico sino la sostenibilidad del hábitat, se incorporaron materiales sostenibles, para luego realizarse nuevas mediciones, a partir de las cuales se determinó que los nuevos materiales mejoraron el confort térmico del hábitat, al comprobarse un aumento de 6°C en la temperatura media interior.

Palabras clave
hábitat, materiales alternativos, diseño sustentable, balance térmico

ABSTRACT

This article evaluates how the incorporation of sustainable materials improved thermal comfort in a habitat using the self-build process, in the San José de Bosa neighborhood in Bogota, Colombia. The problem of comfort was addressed as a fundamental condition of the habitat. The habitat responds to a need for shelter, understood as the need to have one's own space regardless of the way this space responds to climate variables. The use of sustainable materials provides environmental benefits, especially for large cities due to the current high levels of pollution (Fernández-Agüera, Domínguez-Amarillo, Alonso, & Martín-Consuegra, 2019). In these peripheral neighborhoods, cement, brick and steel are the most commonly used construction materials. A case study was carried out in which periodic measurements were made with the objective of determining the thermal balance and how the materials used responded to the existing climate conditions. In order to improve not only the thermal comfort but also the sustainability of the habitat, sustainable materials were used. Finally, new measurements were made to determine if the new materials improved the thermal comfort of the habitat and an increase of 6 °C in the average indoor temperature was established.

Keywords
habitat, alternative materials, sustainable design, thermal balance.

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INTRODUCTION

This article is the result of an academic research project whose main objective is the thermal analysis of an informal habitat in the process of self-construction located in Bosa, a popular district located south west of Bogotá. The study determined that, with the incorporation of a sustainable constructive solution, it is possible to optimize thermal comfort in a self-built habitat. The thermal analysis in this type of informal housing has not been studied in Colombia, however there is background on this issue in other Latin American cities, such as Guayaquil (Ecuador) where case studies have been carried out revealing that used materials, especially on the roof, did not generate thermal comfort (Macias, Soriano, Sanchez and Canchingre, 2015).

The comparative analysis of different works and investigations could determine that in developed countries there are some differentiating factors: there is a very clear regulation that obliges construction companies to comply with minimum quality standards, especially around used materials, in addition to having parameters for evaluation of thermal and acoustic comfort. In some Latin American developing countries it has been shown that the popular and self-built habitat does not take into account bioclimatic aspects or referred to thermal comfort, and that materials used are reused or they are temporary, due to the informality of the built habitat.

The project evaluated the improvement of thermal comfort in a self-built habitat, with traditional materials, cement, brick, reused materials, zinc tiles, asbestos cement tiles and wooden elements, among others. Existing materials were replaced by construction elements obtained from the recycling of Tetrapak containers and insulation of vegetal origin. The investigation was able to determine that the constructive element that most affected the thermal comfort of the habitat was the roof, for this reason it was replaced by incorporating sustainable materials that strengthened the thermal insulation of the habitat and, therefore, increased the thermal comfort of the interior of the habitat object of the study.

STATE OF THE ART

Thermal comfort is defined in ISO 7730 as "that condition of the mind in which satisfaction with the thermal environment is expressed" (Robledo-Fava *et al.*, 2019)we analyze the influence of the designer's choice of values for the human metabolic index (met. Although this definition is widely accepted, its translation into quantifiable physical parameters is difficult. Basically, and in general terms, man qualifies an environment as comfortable when no type of thermal discomfort is present. The first comfort condition is thermal neutrality, which means that the person does not feel too hot or too cold (Godoy Muñoz, 2012).

In the last 30 years, this concept has taken a very relevant character in the design and construction of homes, the product of engineering advances, air conditioning systems and air conditioning. The various social and energy consumption implications that this entails make it necessary to analyze and reinterpret traditional ways of life in regions with tropical climates, and to seek solutions directly related to bioclimatic architecture. For example, naturally ventilated buildings not only give occupants a sense of comfort and consume less energy, but are also linked to their culture with a particular way of understanding the interior-exterior relationship and even privacy (Godoy Muñoz, 2012).

In addition to bioclimatic aspects, it is important to mention Fanger's theories, based on experiments carried out on 1296 young people in thermal chambers, where static heat transfer models were used. In these studies, clothes and activity of participants were analyzed, while they were exposed to different thermal environments. Participants should indicate how they felt in relation to heat and cold, using the seven points of the ASHRAE thermal sensation scale, from (-3) to (+3), which considers only integer values and where negative values represent the sensation of cold; the positive ones, the heat one; and the value 0, the neutral thermal sensation. Another part of the study was that the participants controlled the environmental thermal conditions, adjusting them until they felt in comfort. Fanger's model combines theories of thermal balance with physiology and thermoregulation to determine a range of comfort temperature, where occupants of the building feel good. According to these theories, the human body uses physiological processes such as sweating, tremor and vasodilation with the aim of maintaining the thermal balance between the heat produced by the metabolism and the loss of heat throughout the body. Maintaining this heat balance is the first condition to achieve a neutral thermal sensation. However, Fanger observed that man's thermoregulatory system is so efficient that it is capable of creating thermal equilibrium within wide limits of environmental variables, even if there is no comfort (Godoy Muñoz, 2012).

To be able of predicting conditions where thermal neutrality takes place, Fanger investigated physiological processes of the body that occur near neutrality. Finally, he determined that the only physiological processes that influence the thermal balance in this context are: the average skin temperature and the rate of sweating, processes that are a function of the level of activity. With subsequent investigations, Fanger obtained a linear relationship, precisely between activity level and sweating rate. Another investigation, where participants with standard clothing took part in a series of tests inside a thermal chamber while performing four

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different activity levels, served to demonstrate a linear relationship between activity level and skin temperature. After replacing these two values with their respective linear regressions in the thermal balance equation, Fanger obtained his comfort equation, which predicts the necessary conditions for the occupant to feel thermal neutrality (Macias *et al.*, 2015).

The analysis of thermal comfort is a recurring theme in case studies and analyzes of energy consumption associated with the sustainability of a construction. In the last five years it was noted that developing countries are beginning to incorporate sustainability concepts associated with the resolution of typical problems in the region, such as earthquakes and the use of recycled materials (Sekhar and Nayak, 2018). An example of this new trend is the development of a floor built on recycled tires that absorb the movements produced by an earthquake, destined to the construction of habitats in Ecuador.

Traditionally, these studies focused on measuring the interior and exterior spaces in order to determine the physical characteristics of materials, energy consumption related to regulations of the country where research was conducted. Today, there is a growing concern in Western Europe that greater insulation and sealing of residential buildings increases the risk of overheating. In this sense, Jones, Goodhew and de Wilde (2016) carried out temperature monitoring of two identical houses in the southwest of the United Kingdom that were built with low energy standards (Code for sustainable homes Level 5). Temperature data were examined using the established static overheating criteria (CIBSE A Guide) and an adaptive thermal comfort standard (BSEN15251). It was found that houses can be considered uncomfortably warm during summer and have the risk of overheating. The study suggested that occupant behavior plays an important role in reducing or increasing internal temperatures.

Likewise, thermal comfort has been associated with the consumption of natural resources which affects the environment of the respective region. That happened in the state of Jammu and Kashmir in India, which experienced a severe energy crisis due to low energy availability *per capita*. Such a situation forced the population to extensive wood consumption, which led to the deforestation of the environment, so it was mandatory to move towards a complete sustainable energy strategy. A study (Ahmed, Qayoum and Mir, 2019) was able to determine that efficient and sustainable thermal insulation of buildings was a great opportunity to generate and encourage energy savings. This focused on the use of new insulating materials that incorporate recycled and sustainable components. The constant use of insulating materials in buildings, not only reduced energy consumption, but also reduced the emission of greenhouse gases and provided better indoor thermal comfort. In this way, natural insulators such as sheep wool, goat wool and horsehair were used, which are better processed and characterized in terms of moisture absorption, thermal conductivity, thermo-gravimetric analysis (TGA) and differential scanning calorimetry (DSC).

Among other of the reviewed works, Fernández, Domínguez, Alonso and Martín (2019), on thermal comfort and indoor air quality (IAQ) in residential buildings with different degrees of tightness, stand out in two climates in Spain. The project compared the behavior of the occupied areas during the day and at night. The IAQ of the buildings studied, erected before the energy efficiency regulations were in force (1939-1979) and lacking mechanical ventilation, their tightness was compared. The reason for that approach was that, in such circumstances, the air change depends on uncontrolled natural ventilation (=open windows), consequently, on the outside temperature. Relative humidity was also taken into account, given the condensation that it can be induced when ventilation is insufficient. Finally, it was determined that, in winter, in both climates, CO_2 levels were higher than 1200 ppm, with averages of the order of 1900 ppm in Madrid and 1400 ppm in Seville, and higher during the night than during the day. Air changes every hour, mediated by infiltration, seemed to be insufficient to keep the house in healthy conditions, in addition to presenting a high risk of surface condensation in the more hermetic houses. That is, and despite having forced ventilation, buildings needed natural ventilation.

Finally, it is worth mentioning the research of Chowdhury and Neogi (2019), whose purpose was to analyze the thermal performance of walls and roofs, commonly used in the residential construction sector in India. This was done by determining the overall heat transfer coefficient or the U value, using the protected hot box test facility. The general test procedure agreed with BS EN ISO 8990: 1996. Subsequently, the effect of the variation of the differential air temperature on the overall heat transfer coefficient of the reinforced concrete roof and three types of typologies used in the construction of brick walls made of baked clay was studied. From the regression analysis, the U value of walls and roof could be easily evaluated for any differential temperature, as experienced by buildings in various climatic zones in India. It was also possible to determine that buildings provided thermal comfort through the interaction between the external environment and the building elements that comprise it, walls, roofs and glazing. A good recognition and previous analysis of the thermal performance of materials used in walls, roofs and glazing can, in short, help to estimate the heating or cooling loads in the proposed ventilation and air conditioning systems.

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METHODOLOGY

This project presents a case study, in which two methods were used: the first one, defined by the protocol given by ISO 7730 standard, corresponds to the analysis of climatological aspects of the environment, common in this type of studies (temperature, humidity, wind speed, among others); and the second, characterization of the existing materials that aims to assess its thermal inertia through static thermal comfort analysis tools (Mahoney figure and Givoni diagram).

ISO 7730 Fanger Method states that not only thermal balance is necessary in a space for thermal comfort; in addition to having an adequate temperature, the following should be taken into account:

a. The characteristics of clothing: isolation and total area of the same.
b. The characteristics of the type of work: metabolic thermal load and air speed.
c. The characteristics of the environment: dry temperature, average radiant temperature, partial pressure of water steam in the air and air speed.

Taking the model as a starting point, the following characteristics were established:

a) Clothing Characteristics
In this case a complete half clothing isolation, 1.0 clo. (clothig). Thermal unit equivalent to thermal resistance of 0.18 m² hr °C/Kcal (Castillo and Huelsz, 2017).
Here, users of the analyzed habitat wore clothes to protect themselves from the cold in the area.

b) Work Characteristics
Considering the metabolic thermal load and air speed, the figure established by UNE ISO 7726: 2002 standard was used, which determines this value based on the characteristics of clothing, the average temperature and the air speed (Figure 4).

c) Environment Characteristics
In this phase of the investigation, all the information on the environment of the analyzed habitat was collected, which was then compared with the data obtained inside the habitat. For this, two devices were used that directly measured the WBGT (Wet Bulb Globe Temperature) thermal index, in addition to the temperature, humidity and temperature of the black balloon. The instrument used was the HT30 Extech model: a measure of air speed and humidity (Figure 1).

The measurements were made between 2:00 p.m. and 5:00 a.m., periodically, once a week, during the months of August, September and October, and the external data were compared with the data inside the habitat (Figure 7). It is necessary to clarify that in this case for the calculation of

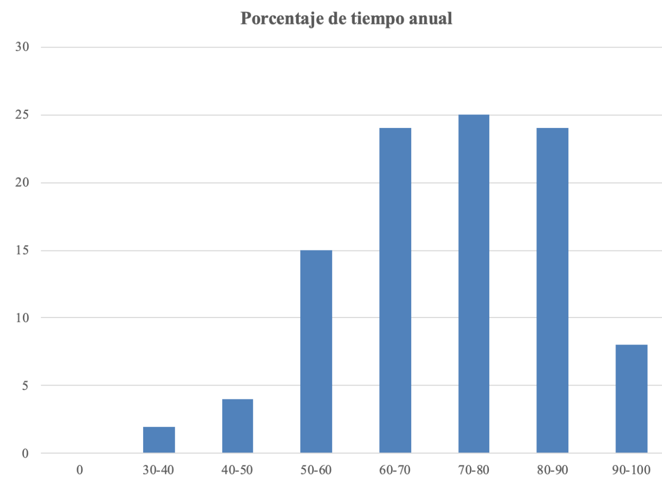

Figure 1. Air temperature. Source: Made by the author.

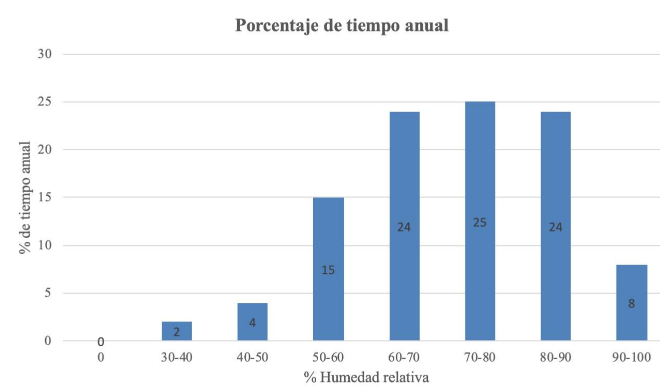

Figure 2. Relative humidity. Source: Made by the author.

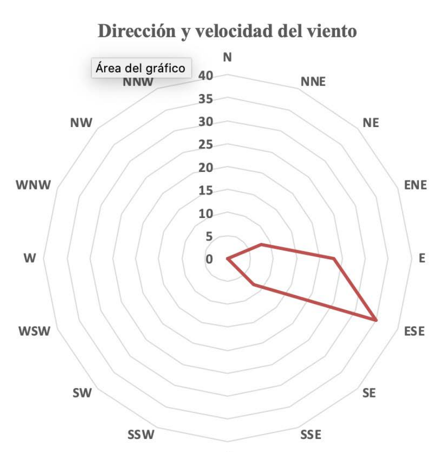

Figure 3. Wind rose of the area. Source: Made by the author.

Clothing Clo	Operating Temperature °C	Relative air speed m/s							
		<0,10	0,10	0,15	0,20	0,30	0,40	0,50	1,0
0,5	18	-2,01	-2,01	-2,17	-2,38	-2,70			
	20	-1,41	-1,41	-1,58	-1,76	-2,04	-2,25	-2,42	
	22	-0,79	-0,79	-0,97	-1,13	-1,36	-1,54	-1,69	-2,17
	24	-0,17	-0,20	-0,36	-0,48	-0,68	-0,83	-0,95	-1,35
	26	0,44	0,39	0,26	0,16	-0,01	-0,11	-0,21	-0,52
	28	1,05	0,98	0,88	0,81	0,70	0,61	0,54	-0,31
	30	1,64	1,57	1,51	1,46	1,39	1,33	1,29	1,14
	32	2,25	2,20	2,17	2,15	2,11	2,09	2,07	1,99
1	16	-1,18	-1,18	-1,31	-1,43	-1,59	-1,72	-1,82	-2,12
	18	-0,75	-0,75	-0,88	-0,98	-1,13	-1,24	-1,33	-1,59
	20	-0,32	-0,33	-0,45	-0,54	-0,67	-0,76	-0,83	-1,07
	22	0,13	0,10	0,00	-0,07	-0,18	-0,26	-0,32	-0,52
	24	0,58	0,54	0,46	0,40	0,31	0,24	0,19	0,02
	26	1,03	0,98	0,91	0,86	0,79	0,74	0,70	0,58
	28	1,47	1,42	1,37	1,34	1,28	1,24	1,21	1,12
	30	1,91	1,86	1,83	1,81	1,78	1,75	1,73	1,67

Figure 4. Activity level 1.2 met. Source: Made by the author.

the operating temperature only daytime temperature was taken into account since nighttime temperature is outside ranges established by the standard (Figure 4).

These are the values that were taken for the calculation:
Tg: 17.7; Ta:16.2 ; Va:0.20 m/s ; Hr:67% ; M:1.2met.

Night measurements allowed determine that the habitat does not present thermal comfort from 9:00 p.m., due to the low outdoor temperature; the analyzed habitat does not have materials that maintain this operating temperature.

Before determining the operating temperature it is necessary to calculate the average radiant temperature:

Tr= tg+1, 9
Tr= 17, 7+1, 9
Tr=18.74
To= A.ta+(1-A).tr
To= 0,6. 16,2+ (0,4).18, 74

TO=17,21°C

ANALYSIS OF THERMAL BALANCE CORRESPONDING TO EVALUATED CONDITIONS

The geographical area studied was the district of Bosa in the south of Bogotá, which has temperature variations between day and night: during the day the average temperature is around thermal comfort indexes (18-20 degrees Celsius) (IDEAM, 2007). With this temperature materials used so far would work correctly, however, at night and early morning the minimum temperatures are 7.6 degrees Celsius and the relative humidity reaches 70%, increasing the thermal sensation of cold. From these measurements, two traditional tools were used in this type of analysis: the Mahoney Figure and the Givoni chart (Figures 5 and 6).

In the figure of Mahoney it is specified that walls and roof must have materials with a high thermal inertia (at the time of the analysis, the roof had a low thermal inertia) and that the habitat should have openings between 15 and 25% on facades (Figure 5).

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ESTRÉS TÉRMICO

	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
DÍA	Confort	Confort	Confort	Confort	Confort	Confort	Confort	Confort	Confort	Confort	Confort	Confort
NOCHE	Frío	Frío	Frío	Frío	Frío	Frío	Frío	Frío	Frío	Frío	Frío	Frío

INDICADORES

	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
H1 Ventilación esencial (calor y humedad)												
H2 Ventilación deseable (calor y humedad)												
H3 Protección contra la lluvia												
A1 Inercia térmica	X	X	X	X	X	X	X	X	X	X	X	X
A2 Dormir fuera												
A3 Problemas con el frío												

RECOMENDACIONES ARQUITECTURALES

PLAN MASA Planos compactos con patios interiores
ESPACIO ENTRE EDIFICIOS Planos compactos
CIRCULACIÓN DEL AIRE Circulación del aire inútil
DIMENSIONES DE LAS ABERTURAS Pequeñas, 15 a 25% de la superficie de los muros
POSICIÓN DE LAS ABERTURAS
PROTECCIÓN DE LAS ABERTURAS (*) Protección contra la radiación solar directa
MUROS Construcción pesada para fuerte inercia térmica; desfase horario superior a 8 horas
TEJADO Construcción pesada para fuerte inercia térmica; desfase horario superior a 8 horas
ESPACIOS EXTERIORES (*)

Figure 5. Mahoney figure for the Bosa area. Source: Made by the author.

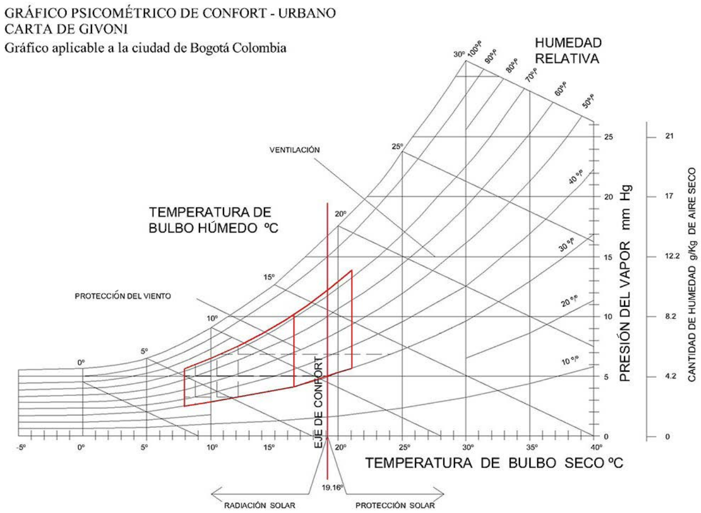

Figure 6. Givoni chart. Source: Made by the author.

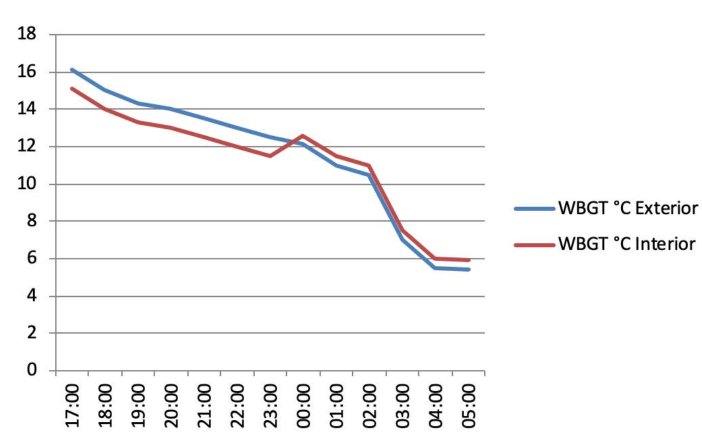

Figure 7. Average outdoor and indoor temperature between 5:00 p.m. and 5:00 a.m. Source: Made by the author.

From this initial analysis, the project focused on the housing roof, taking into account materials and analysis of the interior temperature drop (Figure 7).

ROOF

In order to increase the thermal comfort of the habitat in a sustainable way, a characterization of materials used in the existing construction was carried out considering its density, specific heat, thermal conductivity and thermal diffusion (Figure 9). Based on the data obtained and also the variables "economy", "sustainability" and "thermal conductivity", the most viable materials were selected, in order to mitigate the shortcomings detected in the thermal study performed (Figure 10).

Although fiber cement and Tetrapak had similar prices, other favorable aspects were found to use the latter: a slight decrease in thermal conductivity and low pollution generated by a material that is the product of recycling. However, it was found that, if only one tile of this material was used, the necessary thermal insulation was not obtained, so, in addition to the outer tiles, Tetrapak sheets were used to form a false ceiling that would allow the habitat to have an air chamber between the two elements (Figure 10).

To respond to the demands of users, the decision was made to change the current roof built in zinc on a wooden structure in poor condition. The new roof was built in Tetrapak, using the existing wooden beams - which were cleaned and reinforced - with a false ceiling of sheets, whose thickness was 2cm and it was manufactured with the same material in order to create an insulation that mitigates the low night temperatures detected by the climatic analysis of the area. Hay cubes with a height of 30cm were added as thermal insulators; material that was selected for its low thermal conductivity, its low price and its vegetable origin, which entails a very low charge for CO_2 emissions. The use of sustainable materials is directly related to its geographic availability, one of the variables taken into account for the calculation of

Material	Density (kg/m³)	Thermal conductivity (W/(m·K))
Zinc roof tile	7140	106-140
Masonry brick	1700	0,658
Pine wood	650	0,163
Glass	2700	0,81
Fiber cement roof tiles	1250	0,36

Figure 8. Characterization of materials used in the construction of the house. Source: Made by the author.

Description	Density kg/m³	Thermal conductivity W/m² °C	Price USD	carbono footprint kg/CO²
Fibrocement	1250	0,36	$9	11,84
Sandwich panel	50	0,024	$28	12,5
Polyester	38	0,04	$15	15,04
Tetrapak	900	0,25	$8	0,5

Figure 9. Characterization of materials that improve thermal insulation. Source: Made by the author.

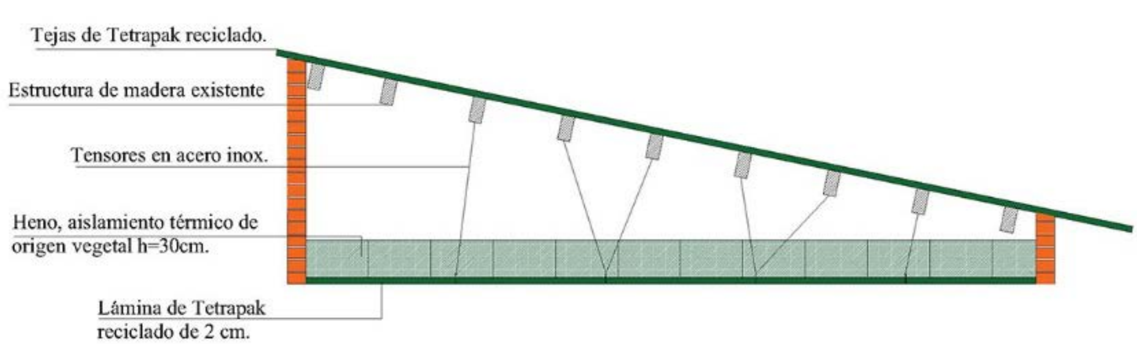

Figure 10. Section of the proposed new roof. Source: Made by the author.

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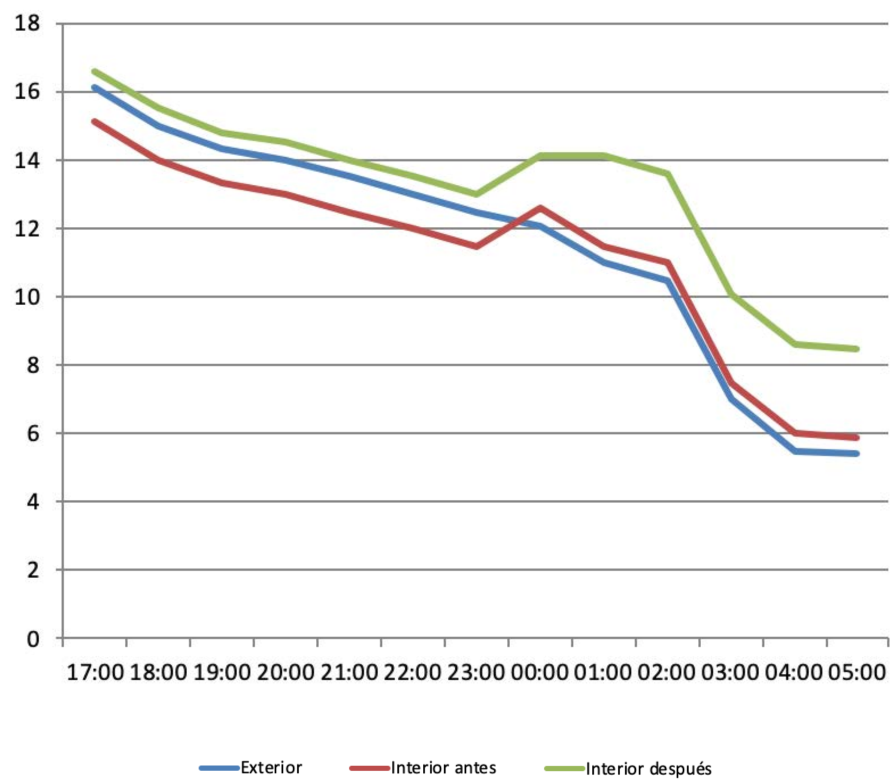

Figure 11. Average temperature before and after the proposed solution. Source: Made by the authors.

Material	Price/m²	CO² kg
Fiber cement roof tiles	$9	11,85
Tetrapak roof tiles	$8	0.5

Figure 12. Fiber cement and Tetrapak. Price and CO2. Source: ITEC (www.itec.cat.).

the carbon footprint of any material (Sekhar y Nayak, 2018).

RESULTS

At this point, the temperature increase inside the habitat was checked and new measurements were made to determine the average temperature, humidity and thermal stress index. Likewise, measurements before and after the incorporation of the new roof were compared, observing that the difference between the outside and inside temperature was expanded by 6 degrees, so that early morning it was possible to reach an average of 13 degrees inside the habitat (Figure 11).

The analysis of weather measurements yielded the following results: the selected habitat did not show thermal comfort at night or in the early morning; the thermal inertia of materials used in its construction was very low; materials reused both on the facade and on the roof (sheets, zinc and asbestos cement tiles, which have a thermal inertia of 0.8 (W/(m • K)), did not contribute to optimizing thermal inertia. Therefore, it was determined that it was necessary to replace these temporary enclosures used in the construction of the housing cover, which affected the thermal comfort of the analyzed habitat (Figure 7).

Climatological analyzes in which temperature and humidity measurements were made allowed to determine the WBGT (Wet Bulb Globe Temperature) index of thermal stress and to establish that the difference between the external and internal temperature ranged between one and a half degrees Celsius. However, the

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temperature in this area of Bogotá between 3 and 5 a.m. is close to 5 degrees, that is, users were really exposed to very low temperatures and outside the operating temperature of thermal comfort (17,21 ° C), which certainly approached those that a street citizen supports in this city (Figure 11). However, an increase of 1°C was detected after 11:00 p.m. due to the use of appliances, mainly television.

This study could establish that it is possible to increase the thermal comfort of an informal habitat using sustainable materials, which can be a role model in neighborhood improvement plans, proposed by the local government, that is, replacing a procedure in which highly polluting materials, such as cement and steel, have always been used by one in which other materials generated from recycling are used.

This project demonstrated that it is possible to build a sustainable habitat (by using recycled materials and limiting the use of cement) without affecting the budget allocated for its construction and, in turn, improving thermal comfort. This finding can be implemented in the current housing improvement policies proposed since the 1980s and where sustainability was not a variable taken into account for the development of the standard. It was calculated that the use of Tetrapak in this improvement allowed reducing CO_2 emissions by 80% (Figure 12).

DISCUSSION

It is necessary to emphasize that all Latin American thermal comfort studies place special emphasis on finding economic solutions that mitigate climatic conditions, with the main objective of reducing the use of air conditioning systems, given the high costs of installation, maintenance and high electrical consumption associated with its use. However, it should be clarified that the sustainability of this objective is not evident to the population. It is very interesting, in that sense, to find studies such as that of *Macias et al.* (2015), which evaluated the solar reflectance of roofs of houses in Guayaquil, Ecuador, in order to reduce the use of traditional air conditioning systems, and concluded that the use of steel plate lowered the interior temperature thanks to the increase in the reflectance.

Although it was determined that the economic variable is not the only one at stake, some of the Latin American research related to comfort has focused on other aspects, including: psychological perception in Brazil (Silveira Hirashima, de Assis and Nikolopoulou, 2016) , study cases that analyze the relationship between lighting and hydrometry in Argentina (Boutet, Hernández and Jacobo, 2020), and a proposal for a new adaptive comfort model in Chile, which seeks to adapt the lower limit of the thermal comfort threshold in order to develop a standard that better reflects the needs of inhabitants and the socio-economic culture (Pérez-Fargallo *et al.*, 2018)including adaptation to external temperatures, opening windows and changing clothing. In this regard, two international standards provide the fundamental basis to model the necessary equations: EN 16798 (formerly 15251. This also highlights the work of Castillo and Huelsz (2017) where it was determined that thermal comfort produced when there is natural ventilation in hot climates in Mexico defines bioclimatic strategies for existing urban spaces, based on morpho-typological components, urban microclimate conditions and comfort requirements for all types of citizens in Mexico and Spain.

The definition of thermal comfort specifies that: "The energy consumption or internal temperature of a given space, under certain loads, can be established considering thermal comfort standards; therefore, it is still crucial to properly define those standards to achieve user comfort and reduce energy consumption." (Pérez-Fargallo *et al.*, 2018, p. 95). That is, it is about neutralizing or avoiding harmful weather conditions and enhancing the good ones in relation to the comfort of users.

The first studies and research on thermal comfort initially focused on the use of clothing in winter and summer seasons (Heathcote, 2011). This methodology was taken to architecture, to space conditioning, to weather conditions: air conditioning, ventilation, window opening, insulation, among other measures.

It should be noted that in Latin American countries located in the tropics it is not usual to implement heating systems or air conditioning. This type of system is only used by large companies and hotel chains.

Specifically, in the informal housing analyzed, materials used were temporary, with the objective of simply protecting themselves from the weather; the habitat owner was not aware of dangers associated with the use of prohibited materials in other countries, such as asbestos cement. In Colombia, regulations prohibit it since 2019.

CONCLUSIONS

The habitat studied in the research exposed here presented deficiencies in its construction process due to the temporary nature of materials used for its construction. The main objective of the work, to increase the thermal comfort of this habitat, was partially fulfilled, because the only building element that could be optimized was the roof, due to time and money limitations of the project.

However, the use of recycled materials is not an unprecedented aspect in research focused on sustainable housing, as Spagnoli explains: "It should be noted that panels and furniture of interior walls are made of recycled materials, mixed with agglomerates to increase project sustainability and reduce expenses" (2020, p. 163).

The analysis and characterization of the materials that could be used in habitat improvement was the technical tool that allowed justify the use of Tetrapak, whose decisive qualities were its low price and the low CO_2 emissions generated in its manufacturing process.

From this analysis, the need to incorporate international standards of thermal comfort in the construction of housing aimed at the lowest social classes is revealed in countries where they are not contemplated and, in this way, to avoid that in the processes of self-construction, such as the one under study, thermal comfort or the use of prohibited materials in other countries are not considered, such as asbestos cement.

Not all the materials raised in principle could be used in the project: one of the objectives was to implement the use of earth in urban informal habitats, however, the respective owner stated that he was not interested, nor authorized its use, because of the fragility of the material and because it was not possible to guarantee the safety on the facade of the habitat.

However, the incorporation of a sustainable material guarantees the sustainability of these types of habitats, that is, it is possible to build a sustainable habitat using recycled materials and low prices.

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THE GEOTHERMAL COOLING POTENTIAL FOR BUILDINGS IN ARID ZONES

POTENCIAL DE ENFRIAMIENTO GEOTÉRMICO PARA EDIFICACIONES EN ZONA ÁRIDA

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RESUMEN

En el presente artículo se analiza cuantitativamente el potencial geotérmico para ser usado como sistema pasivo de refrescamiento edilicio en un ambiente árido urbano, tomando como caso de estudio el Área Metropolitana de San Juan (República Argentina). Se utiliza como insumo la base de datos climáticos y meteorológicos correspondiente a la estación verano, obtenida en el Complejo Universitario Islas Malvinas (CUIM) de la Universidad Nacional de San Juan, lugar donde el Instituto de Estudios en Arquitectura Ambiental "Arq. Alberto Papparelli" (INEAA) registra: temperatura del suelo, a distintas profundidades, y parámetros meteorológicos ambientales. Los resultados están relacionados con la identificación de gradientes y profundidades óptimas para el aprovechamiento del recurso como Sistema Pasivo de Refrescamiento Geotérmico, a fin de proveer condiciones de confort higrotérmico en zonas urbanas áridas durante el verano. En promedio, se obtiene una diferencia máxima de 8,7°C entre la temperatura del aire y la de la tierra, a una profundidad de 3m. La longitud de los conductos enterrados necesaria resulta de 64m para una velocidad del aire de 3m/s, la cual se reduce a 27m para una velocidad de aire de 2m/s.

Palabras clave
arquitectura bioclimática, sistemas pasivos, ahorro energético.

ABSTRACT

In this article geothermal potential is quantitatively studied to be used as a passive building cooling system in an arid urban environment. The San Juan Metropolitan Area, Argentina is taken as a case study. A climate and weather database for the summer season was used as input. It was generated at the National University of San Juan's Islas Malvinas University Complex (CUIM), where the Arq. Alberto Papparelli Institute for Studies in Environmental Architecture (INEAA) records data on soil temperature at different depths and meteorological parameters in the environment. The results identify gradients and optimal depths to use this resource as a passive geothermal cooling system in order to provide hygrothermal comfort in arid urban zones during the summer. There was an average maximum difference of 8.7 °C between the air temperature and the ground temperature at a depth of 3m. The required length of the buried tubes is 64m for an air speed of 3 m/sec, which decreases to 27m for an air speed of 2m/s.

Keywords
bioclimatic architecture, passive systems, energy savings

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INTRODUCTION

Passive thermal conditioning systems for homes are presented as a valid alternative to achieve hygrothermal comfort, particularly for those who cannot access the use of systems that employ conventional energy, due to their high cost. The energy savings that would be obtained with the implementation of the concept of sustainable architecture specifically in the planning and execution of social housing would produce a great impact on the demand of the local energy matrix, since this energy saving could be used in production activities. At the same time, through this perspective, a reduction of dangerous CO_2 emissions into the atmosphere is achieved (Kurbán, Cúnsulo, Álvarez, Montilla and Ortega, 2015).

The province of San Juan is located in the center-west of the Argentine Republic (south latitude 31° 32'; west longitude 69° 31'), in the arid South American diagonal. The San Juan Metropolitan Area (AMSJ), located to the southwest of the province, presents an arid urban climate (Thornthwaite index = 0.0794) and continental (Gorczynsky [K] = 34.12). It has high thermal amplitudes, both daily and seasonal and annual (17.3°C), low humidity levels (annual average = 40.92%), summer regime of low rainfall (annual = 77.72mm), high solar radiation throughout the year (490W/m^2), as a result of an increasingly reduced cloudiness, and a water deficit of 979.28mm. Throughout the year, the most frequent wind is from the southern sector (average 7km/h), with intense gusts associated with dust storms, sometimes due to a change in weather. In fact, before the weather changes, a local wind called "*zonda*" usually appears, which constitutes a föhen effect, characterized by very dehydrated and torrid air that can last from a few hours to several days (Kurbán *et al.,* 2015).

In summary, the study area has resources that can be used to provide hygrothermal comfort responses to the population, while at the same time it involves a highly sustainable strategy by directly influencing energy savings and, with it, reducing environmental pollution (Kurbán *et al.,* 2015; Cabezas, 2013). Whenever building thermal conditioning systems are designed it is very important that their efficiency is validated through simulation programs in order to assess the relevance of their application (Flores Larsen and Lesino, 2001).

The basic design inputs of most passive systems are records of temperature, solar radiation, relative humidity and winds; usually difficult to get for urban areas. Hence the importance of the urban meteorological data bank obtained at the INEAA, with 20 years of continuous records, which allows studies with accurate and reliable data.

The use of passive and/or hybrid systems to condition the air entering the buildings has gained increasing acceptance in recent years due to economic savings achieved in energy requirements necessary for thermal conditioning (Flores Larsen, Hernández, Lesino and Salvo, 2001; Bansal, Misra, Agrawal and Mathur, 2010).

The same does not happen when the passive system is geothermal cooling. In San Juan, prior to the completion of the project that gave rise to this article, there were no records of temperature or soil moisture with geothermal passive use objectives. To perform some kind of resource estimation, data extracted from other regions with climatic and edaphic characteristics generally different from this area were used. This lack of data made the possible applications of a strategy used in other latitudes with good bioclimatic results unreliable. Aridity conditions intervene directly in the thermophysical properties of the earth, so it is not valid to simply extrapolate applications to other urban environments of different geographical contexts.

Earth behaves like a great collector and accumulator of energy. The soil has many potentially valuable thermal properties due to its high heat capacity and high thermal inertia. With an average density of 1800-2500kg/m^3, it has a specific heat of 920J/kg°K and an average thermal conductivity of 0.3W/m°K (compared to 0.58W/m°K for water and 380W/m°K for copper). The volumetric thermal capacity of soil is around 2MJ/m3°K compared to 4.5MJ/m3°K of water (Iannelli and Gil, 2012). On the other hand, its low thermal conductivity makes the penetration of heat into the soil very slow, as well as its cooling (Xamán *et al.*, 2014, Ahmed, Ip, Miller and Gidado, 2009).

The thermal properties of the soil mean that diurnal temperature variations do not penetrate beyond 0.5m, but annual temperature variations reach a depth of about 4m. Beyond these depths, the temperature of the earth remains constant throughout the year (Iannelli *et al.,* 2013).

The systematization of geothermal exploitation can be carried out using the air fluid for thermal transfer. In that case, buried pipes are used whose function is the summer or winter air conditioning of ventilation air. The system consists of circulating air from outside to inside the building through underground conduits, which allow heat exchange (Vidal and Vidal, 2011, Bisoniya T. 2015, Tiwari, Singh, Joshi, Shyam and Prabhakant, 2014).

According to Hollmuller and Lachal (2005), the internal temperature that is obtained taking advantage of the geothermal potential is 15°C anywhere in the world, day or night, in winter or in summer, but these authors do not specify the depth of the pipe.

A study carried out in Asunción (Cohenca, Bordas and Schvartzman, 2013) indicates that, at a depth about

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3.5m, there is a stabilization of the soil temperature around 23.5°C. In summer, the average environmental temperature is 28.4°C, which is significantly higher than the average of the soil.

Research carried out in Kusuda (USA) in 1965 determined that the temperature at a depth greater than 2m no longer shows variability and corresponds to the average annual temperature (Baver, Gardner and Gardner, 1991).

In hot climates, the soil temperature in summer is colder than the nighttime outside temperature, but still very warm to produce effective building cooling. Therefore, it is necessary to cool the soil below its natural temperature.

One of the experiences carried out in areas of warm and arid climate, such as San Juan, is that of Neguev (Israel). Due to the desert characteristics of the region, at Ben Gurion University, Boquer Headquarters, it was experienced covering the soil with 10cm of a layer of aggregates, which was wet very early in the morning. The condition was that the soil was not sandy, so that it retained moisture. Monitoring considered 10cm, 30cm and 60cm thick. From the beginning of watering of the layer of aggregates until the soil registered a thermal equilibrium, approximately one week passed; equilibrium that became continuous, provided watering did not cease. If the latter happened, in 5 days the temperature increased (Givoni, 1984).

For Hazim Zaki, Al-musaed and Khalil (2005), buried tube designs exhibit a varied combination in size and shape: some systems have parallel tubes ending in a header, others have a radial collection prototype in a central sump (to facilitate the removal of moisture) and, in other cases, it is only a tube. They further argue that it is important to design the system to minimize cost and maximize benefits, and, on the other hand, that the length of a tube of more than 10m, for example, is inefficient.

Similarly, small diameter tubes are more effective per unit than large tubes; they should be placed as deeply as possible, although no specifications on such depth are recorded (De Paepe and Janssens, 2003; Rouag, Benchabane and Mehdid, 2018).

DATA ACQUISITION

In order to evaluate the real cooling potential of the geothermal system in an arid zone and due to such a disparity of values in the specific bibliography, research is being carried out at INEAA with measurement of temperature and humidity values in situ. Since December 2018, temperature and humidity values of the subsoil are recorded in a suburban area of San Juan (Rivadavia-San Juan), simultaneously with measurements

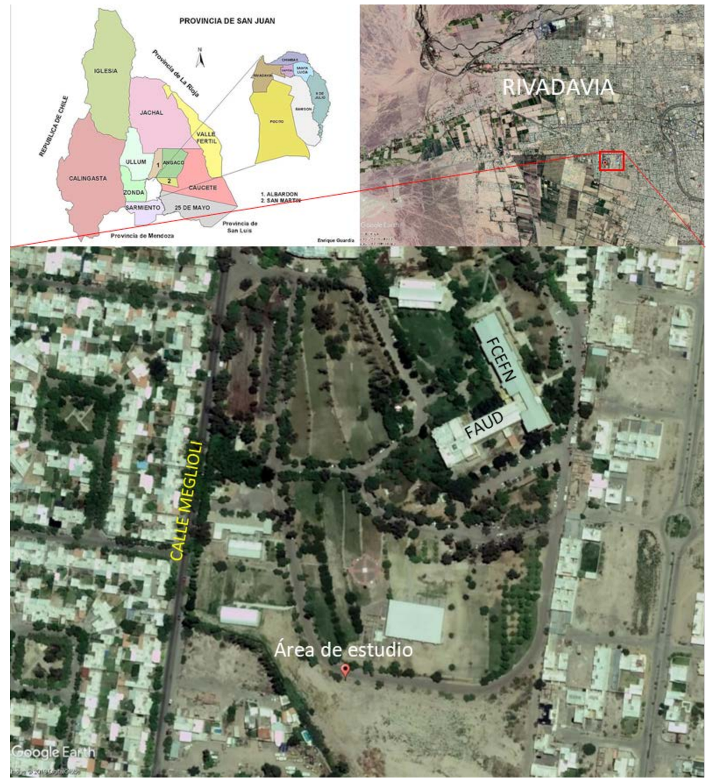

Figure 1. Location of the study area. Source: Pitaluga et al, 2019, p. 4.

of environmental parameters.

The sector under study (Figure 1) is located in Malvinas Islands University Complex (CUIM) of Universidad Nacional de San Juan (UNSJ), a complex that brings together several faculties dependent on the UNSJ. Geographically, it is located in the department of Rivadavia, located west of the capital city of San Juan (Figure 1).

In order to identify the soils present in the study sector and recognize the main characteristics and qualities that allow them to understand their origin, know their physical and chemical properties and be able to classify them taxonomically, a study was conducted (Pittaluga, Ocaña and Cortez, 2019) whose specific objectives were:

- Edaphological characterization of the sector to analyze.
- Determination of physical properties of soils.
- Sampling for characterization of properties in laboratory.
- Taxonomic classification of soils present.

The observation site is located in the proximal portion of the mega-fan of Tulum, a geoform developed in the so-called Tulum Valley, which corresponds to an intermontane depression of tectonic origin, filled with hundreds of meters of Quaternary age river deposits. The

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Figure 2. a) Weather Station b) Calibration c) Placement of thermocouples on the ground Source: Made by the author.

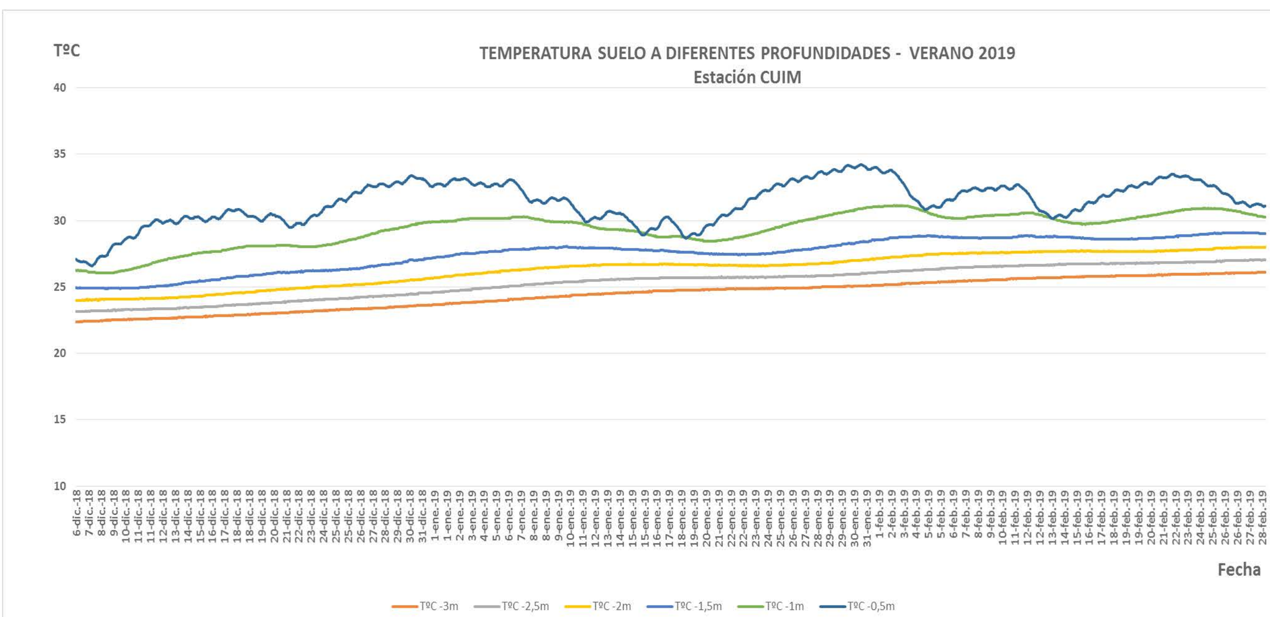

Figure 3. Air and soil temperatures at different depths Source: Made by the author.

samples analyzed have a relatively large block structure that indicates that the soil resists water penetration and movement. The average size of individual aggregates can be classified as *coarse to very coarse* and the degree of development is *very strong*. With the pH analysis, the selected layers also show values ranging from 6.67 to 8.03, from which it is possible to classify the soil as *moderately basic to neutral*. The low content of organic matter in the samples indicates the presence of a young soil, developed in dry and warm climates derived from materials with coarse textures.

For geothermal measurements, pairs of thermocouples from 0.50m to 3.00m deep were installed (Figure 2c), with an interval of 0.50m and a humidity sensor at a depth of 1.5m. The information was stored on a SIM card placed in the electronic control device that received the signal from buried sensors. This information was periodically accessed with a notebook, which was complemented with records from an automatic weather station (Figure 2a and b), which measures temperature and relative humidity of air, solar radiation, rainfall and atmospheric pressure, among other variables. Records of both systems are made with intervals of 1 hour.

TEMPERATURE DATA PROCESSING

The meteorological information collected was processed to obtain summer conditions, considering the period between the months of December 2018,

TIME	-3m	-2,5m	-2m	-1,5m	-1m	-0,5m	EXT	Dif. Air/SoIL(-3m)
0	24,4	25,3	26,3	27,6	29,5	31,5	27,2	2,8
1	24,4	25,3	26,3	27,6	29,5	31,5	26,3	2,0
2	24,4	25,3	26,3	27,6	29,5	31,6	25,6	1,2
3	24,4	25,3	26,3	27,6	29,5	31,6	24,9	0,5
4	24,4	25,3	26,3	27,6	29,5	31,6	24,1	-0,3
5	24,4	25,3	26,3	27,6	29,5	31,6	23,3	-1,1
6	24,4	25,3	26,3	27,6	29,5	31,7	22,7	-1,7
7	24,4	25,3	26,3	27,6	29,5	31,7	22,3	-2,1
8	24,4	25,3	26,3	27,6	29,5	31,7	23,5	-0,9
9	24,4	25,3	26,3	27,6	29,5	31,7	25,1	0,7
10	24,4	25,4	26,4	27,6	29,5	31,7	26,4	2,0
11	24,4	25,3	26,3	27,6	29,5	31,7	27,7	3,3
12	24,4	25,3	26,3	27,6	29,5	31,7	29,0	4,6
13	24,4	25,3	26,3	27,6	29,5	31,6	30,3	5,9
14	24,4	25,3	26,3	27,6	29,5	31,6	31,3	6,9
15	24,4	25,3	26,3	27,6	29,5	31,6	32,2	7,8
16	24,4	25,3	26,3	27,6	29,5	31,6	32,8	8,4
17	24,4	25,3	26,4	27,6	29,5	31,5	33,1	8,7
18	24,4	25,3	26,4	27,6	29,5	31,5	33,1	8,7
19	24,4	25,3	26,4	27,6	29,5	31,5	32,7	8,3
20	24,4	25,3	26,4	27,6	29,5	31,5	31,6	7,2
21	24,4	25,3	26,4	27,6	29,5	31,5	30,3	5,9
22	24,4	25,3	26,4	27,6	29,5	31,5	29,2	4,8
23	24,4	25,3	26,4	27,6	29,5	31,5	28,2	3,8
PROMEDIO	24,4	25,3	26,3	27,6	29,5	31,6	28,0	3,6

Table 1. Average hourly temperature values for summer. Source: Made by the author.

January and February 2019. The pairs of hourly records were averaged at the same depth and, subsequently, the corresponding 60 values at each hour of the day, thus obtaining a record for each hour of the average summer day. Figure 3 shows the ambient temperature and those recorded at different depths of soil, in the period considered.
Average values for each hour of the period studied are shown in Table 1.

Figure 4 shows the seasonal averages for summer of variations in air and soil temperature at different depths.

Although to date the number of records in CUIM is scarce (7 months), measurements made do not confirm the estimates of Hollmuller and Lachal (2005), according to which, anywhere in the world, day or night, in winter or in summer there are soil temperatures of 15°C. Instead, they are closer to what Baver *et al.*, (1991) has upheld, who establish that temperature at a depth of 2m corresponds to the average annual temperature. In this regard, and as indicated by the statistics of urban climate of the Metropolitan Area of San Juan (Ortega, Montilla and Cúnsulo, 2013), temperature at 2m depth is 21.07°C.

For Iannelli *et al.* (2013), thermal properties of the soil mean that diurnal temperature variations do not penetrate beyond 0.5m, but annual temperature variations reach a depth of about 4m. Beyond these depths, the temperature of the earth remains constant throughout the year. Its value is approximately 1.7°C higher than the average value of the annual surface air temperature.

However, it is observed that temperatures recorded by sensors installed in the CUIM show values higher than those indicated by that bibliography.

With the values of soil temperature obtained, two graphs were prepared that show the profile of that climatic variable in the hours of exterior maximum and minimum (07 am and 05 pm). They are presented in Figures 5 and 6, respectively.

APPLICATION OF THE GEOTHERMAL SYSTEM IN THE CLIMATIZATION OF A SOCIAL HOUSING

In order to design the geothermal cooling system, applying it to a three-bedroom bioclimatic housing of social interest (Kurbán, Cúnsulo, Matar, Ripoll and Ortega, 2017), it is based on the calculation of the flow necessary to air condition the volume of the

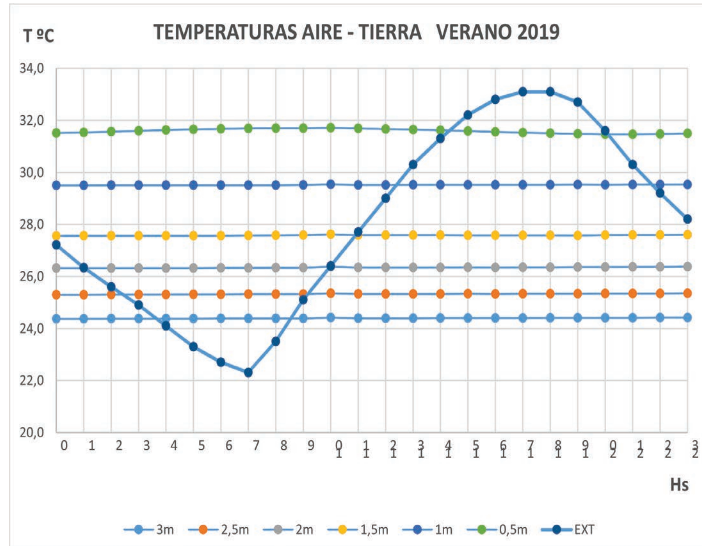

Figure 4. Subsoil temperatures at different depths. Source: Made by the author.

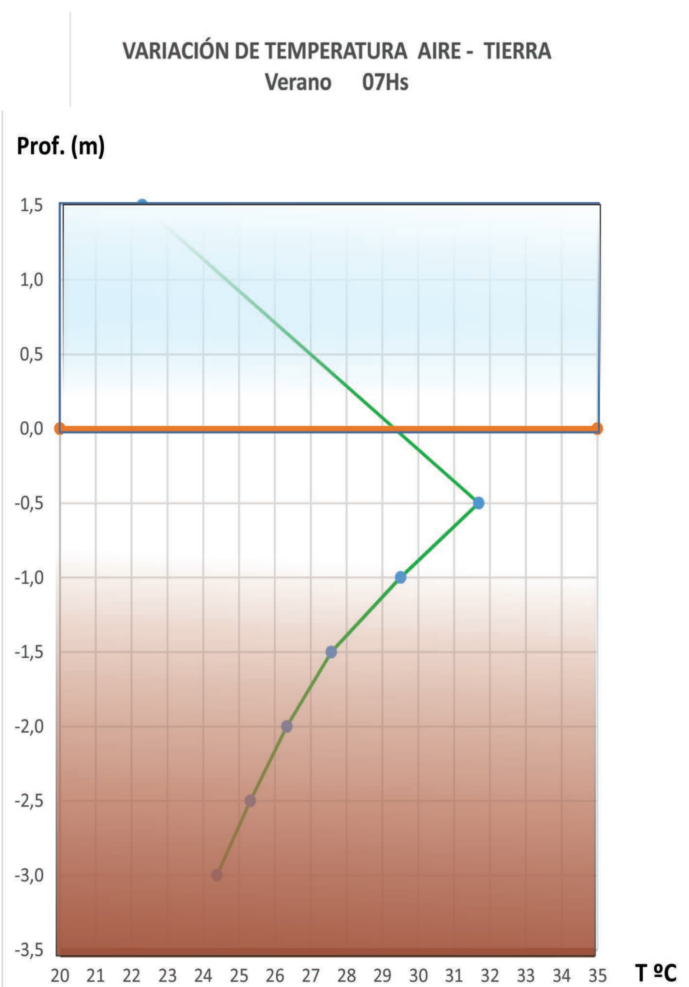

Figure 5. Air and soil temperature profile at 07 am. Source: Made by the author.

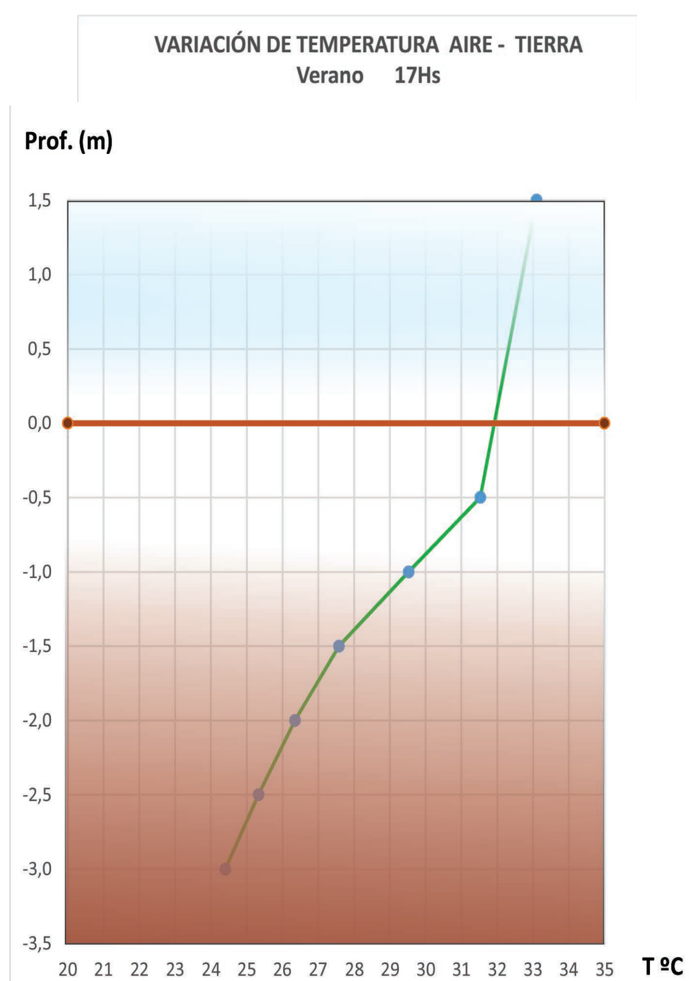

Figure 6. Air and soil temperature profile at 5 p.m. Source: made by the author.

house, which was 212m³/h. Initially, a speed of 3m/s is considered within the PVC conduit of 200mm diameter and 5.9mm wall thickness with a thermal conductivity = 0.17W/m°K.

Air flow that goes through each pipe is given by the following expression:

$$q_t = A * v = \pi\, 0.1^2 m^2 * 3\frac{m}{s} = 0.09\frac{m^3}{s} = 325m^3/h$$

Where
(m²) is the area of the pipe and (m/s) is the velocity of the air in the pipe.
With this value, the quantity of pipes needed is calculated based on the necessary and available flow, according to the section of the selected pipe. It is rounded to the upper integer.

$$n = \frac{q_T}{q_t} = \frac{212m^3/h}{325m^3/h} = 0.65 \rightarrow n = 1$$

That is to say, that with a single tube it is enough to cover the air demand. With this value, the length of the pipe is calculated based on the desired indoor temperature (25°C), the inlet air (33.15°C) and the ground at 3m deep (24.4°C).

To determine the heat exchange surface and the length of the pipe, it is necessary to calculate the average temperature inside the duct T_{ma}.

$$T_{ma} = \frac{(T_{ae} + T_{as})}{2} = \frac{33.15ºC + 25ºC}{2} = 29ºC$$

T_{ae} is the temperature in the inlet of the pipe (°C) and T_{as} the temperature in the outlet.

In order to evaluate the heat exchange between the ground and the circulating air, the thermal resistance of the pipe is calculated (m²°C/W), which is given by the conduction resistance R_{cond} and convection resistance R_{conv}.

$$R = R_{cond} + R_{conv}$$

To define , the thickness of the duct wall (e = 0.0059m) and thermal conductivity (λ =0.17W/m°K) are taken into account

$$R_{cond} = \frac{e}{\lambda} = \frac{0.0059}{0.17} = 0.035m^2ºK/W$$

Convection resistance R_{conv} is a function of air velocity, v(m/s) is given by the expression:

$$R_{conv} = \frac{1}{5.55v^{0.8}} = \frac{1}{5.55 * 3^{0.8}} = 0.075m^2ºK/W$$

Consequently,

$$R = R_{cond} + R_{conv} = 0.035 + 0.075 = 0.11m^2ºK/W$$

The average heat flow per unit area (W/m²) is proportional to the temperature difference between the soil and inside the pipe and inversely proportional to the thermal resistance of the duct wall.

T_{ma} = 29°C = 302 °K
T_{tierra} = 24°C = 297 °K
R = 0.11m²°K/W

$$\phi_m = \frac{(T_{ma} - T_{tierra})}{R} = \frac{302ºK - 297ºK}{0.11m^2ºK/W} = 45.5W/m^2$$

The energy that is necessary to extract from the air inside the pipe is (Ws/m³) and is given by the formula:

$$E_e = \left(\frac{i}{V_e}\right)_{entrada} - \left(\frac{i}{V_e}\right)_{salida}$$

They are:
i : Enthalpy of Dry Air
V_e: Specific Air Volume

From the psychometric chart which considers a relative humidity of 35%, the values of i and V_e are obtained at the inlet and outlet contemplating air temperature at the inlet and outlet, respectively.

Inlet Air Temperature (T_{ae}) = 33.15°C
Relative Humidity = 35%
From the psychometric chart, you get then:
Enthalpy of Dry Air i = 62kJ/Kg
Specific Air Volume V_e = 0.88m³/Kg

Outlet Air Temperature) = 25°C
Relative Humidity = 35%
From the psychometric chart, you get then:
Enthalpy of Dry Air i = 42.5kJ/Kg
Specific Air Volume V_e= 0.85m³/Kg

Replacing the values in the previous formula, you get:

$$E_e = \left(\frac{i}{V_e}\right)_{entrada} - \left(\frac{i}{V_e}\right)_{salida} = \left(\frac{62kJ/kg}{0.88m^3/kg}\right)_{33.1ºC} - \left(\frac{42.5kJ/kg}{0.85m^3/kg}\right)_{25ºC} =$$

$$E_e = 20.45\frac{kJ}{m^3} = 20450Ws/m^3$$

The necessary exchange area S(m^2) results in:

$$S = (E_e * q_t)/\phi_m = \frac{(20450Ws/m^3 * 0.09m^3/s)}{45.5W/m^2} = 40.45m^2$$

To calculate the length of the pipeline, it is necessary to divide the exchange surface, taking into account the diameter (*D*) of pipes.

$$L = \frac{S}{\pi\, D} = \frac{40.45m^2}{\pi\, 0.2m} = 64.3m \cong 64m$$

If the air speed is lowered to 2m/s, the air flow that would circulate through the ducts would be 0.06m^3/s, and the length of the ducts could be reduced to 27m.

CONCLUSIONS

The geothermal cooling system is a good alternative to consider for summer thermal conditioning, especially at times when the outside air temperature is 35°C or more, since a thermal jump of 11°C is achieved. The cooling effect produced by ventilation by the movement of the air driven from the ducts must be added to this (Neila F., Bedoya C. (2001).

The system is not effective in some hours, especially at night, when the temperature of the outside air is lower than that of the ground at 3m depth. In these cases, the nighttime ventilation strategy is more effective, because of the cooling.

The temperature at 3m deep in summer is approximately 3°C higher than the annual average air temperature, with the characteristics of the soil present at the measurement site. This may vary in presence of another type of soil, which should be validated through field studies.

The soil temperature has a tendency to continue decreasing depending on the depth, beyond 3m with the type of soil analyzed. Consequently, a greater thermal jump could be obtained by burying the pipe in greater depth, but the greater cost overrun should be studied in order to assess its feasibility and the amortization time.

From the values found, it can be stated that the implementation of a geothermal system for building cooling is highly beneficial from the point of view of the thermal comfort of the inhabitants and contributes to generating significant money savings in building air conditioning, that is, it collaborates with the sustainability of the human habitat.

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METHODOLOGY FOR A REGIONAL CARTOGRAPHY FOR THE APPLICATION OF THE BIOCLIMATIC STRATEGIES OF THE GIVONI CHARTER

METODOLOGÍA PARA ELABORAR UNA CARTOGRAFÍA REGIONAL Y APLICAR ESTRATEGIAS BIOCLIMÁTICAS SEGÚN LA CARTA DE GIVONI

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RESUMEN

Se plantea como objetivo de la investigación expuesta la viabilidad de una metodología para cartografiar un territorio concreto, implementando las estrategias bioclimáticas necesarias para alcanzar el confort, según el diagrama de Givoni; herramienta muy útil para el diseño de edificios. Tal metodología se desarrolla en cuatro fases: I, obtención de la información climática; II, análisis de los datos climatológicos; III, selección de estaciones y datos mensuales, aplicación de la carta de Givoni e inicio del proceso de cartografiado; IV, establecimiento de la zonificación, y elaboración de mapas, con carácter mensual. Como resultado del trabajo, se obtiene un conjunto de mapas que indican las estrategias bioclimáticas adecuadas a cada territorio, en periodicidad mensual, para alcanzar el confort en los edificios. La metodología fue validada en un territorio concreto en España, utilizado como caso de estudio. En definitiva, la aportación original de la investigación es precisamente el desarrollo de la mencionada metodología, que permite elaborar una cartografía para un territorio determinado -mapa que convierte en una potente herramienta para el diseño bioclimático- y que, además, es susceptible de ser aplicada a cualquier territorio.

Palabras clave
arquitectura bioclimática, cartografía, climatología, territorio

ABSTRACT

The aim of the research is the feasibility of a methodology to map a specific territory, implementing the bioclimatic strategies necessary to achieve comfort, according to the Givoni diagram, as a very useful tool for building design.The methodology used is developed in four phases: I, obtaining the climatic information; II, analysis of climatological data; III, selection of stations and monthly data, application of Givoni letter and start of the mapping process; IV, establishment of zoning, and mapping, on a monthly basis. As a result of the application of the methodology, a set of maps is obtained that indicate the appropriate bioclimatic strategies for each territory, on a monthly basis, in order to achieve comfort in the buildings. The methodology has been validated in a specific territory in Spain, used as a case study. The original contribution of the research is said methodology that allows to elaborate the cartography for a territory, that becomes a powerful tool for the bioclimatic design, and that is capable of being applied to any territory.

Keywords
bioclimatic architecture, cartography, climatology, territory

Metodología para elaborar una cartografía regional y aplicar estrategias bioclimáticas según la carta de givoni
Fernando da Casa Martín, Flavio Celis D'Amico, Ernesto Echeverría Valiente
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INTRODUCTION

BIOCLIMATIC DESIGN ACCORDING TO STRATEGIES OF GIVONI

The bioclimatic design is a tool to reach levels of thermal comfort that has its origin in the study of the relationship of man with the climate. Already at the beginning of the 20th century, Houghten and Yagloglou worked with the concept of climate comfort in their study "Determining lines of equal comfort" (1923), as part of what is now known as ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). This work proposed to locate comfort zones in a psychometric diagram, relating humidity and temperature, based on the effective temperature index. Many investigations were generated from that moment. As evolution to these approaches, the so-called climates, bioclimatic diagrams or bioclimatic charts were established, which are used as tools to determine design strategies of exterior and interior spaces with the aim of achieving thermal comfort. These charts allowed connect climatic conditions of the place with the passive and/or active strategies that are needed to achieve comfort conditions (Givoni, 1969).

In the development of these tools, numerous contributions have been made to analyze the variables involved in these phenomena and the way they do it: Halawa and Van Hoof (2012), Mena, Rodríguez, Castilla y Arahal (2014), Dávila (2015), Larrumbide and Bedoya (2015), Kurbán and Cúnsulo (2017), and Esteves (2018). Most of them focus on the relationships between different thermal variables and human comfort, and their impact on the graphic representation of these relationships.

The most commonly used diagrams, or bioclimatic charts, are those of Olgyay and Givoni, as they are directly applicable to buildings and their surroundings, so that they obtain equally direct recommendations from them. The first quantifies corrections of the bioclimatic parameters to get human comfort in outdoor conditions, without any relation to the architectural object. The second one has the incidents that architecture can produce in the climate and points out the qualities that buildings must have in order to achieve a sense of comfort within them (Couret, Guzmán, Milián, García, and Salazar, 2015; Medina and Escobar, 2019).

The application of Givoni diagram for the bioclimatic design of buildings is in its initial objective. It has been used both in the field of design of concrete construction systems (Balter, Ganem and Discoli, 2016), in specific cases of buildings (Rodríguez, Nájera and Martín, 2018), and in the preparation of bioclimatic architecture manuals for a particular territory (Pérez, Ladrón de Guevara and Boned, 2015). There are also references

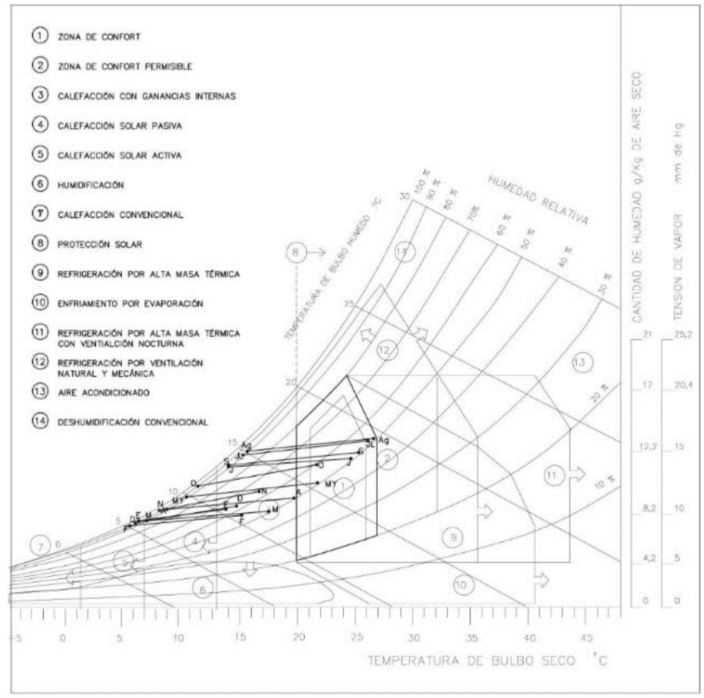

Figure 1. Givoni diagram for the climatic conditions of the data collection period: 2002-2016, at the Lourizán meteorological observatory, Galicia, Spain. Source: Made by the authors.

for Japan (Ooka, 2002), China (Gou, Li, Zhao, Nik and Scartezzini, 2015) and even Latin America (Echeverría, García, Celis and Saelzer, 2019).

The bioclimatic chart of Givoni is based on the Thermal Stress Index (TSI) to delimit the wellness zone, and its application is very suitable in hot climates of arid regions. This method takes into account the characteristics of the construction as modifiers of conditions of the outside climate and recommends the well-being inside buildings.

Givoni (1969) proposes a bioclimatic chart in which dry bulb temperatures are represented in the abscissa axis, while in the axis of the ordinates, the partial tension of water vapor contained in the air, the curved, psychometric lines represent the relative humidity (Figure 1). The wet bulb temperature is located above the maximum humidity line (100%).

The representation of the annual climate can be done with the average conditions of each month. The diagram delimits several zones whose characteristics of temperature and humidity indicate the desirability of using certain design strategies in the building.

Each of these zones can be seen in Figure 1. The heating strategies are successive, while, in the cooling strategies, there is an overlap and, therefore, a range of possibilities with which the comfort area can be reached.

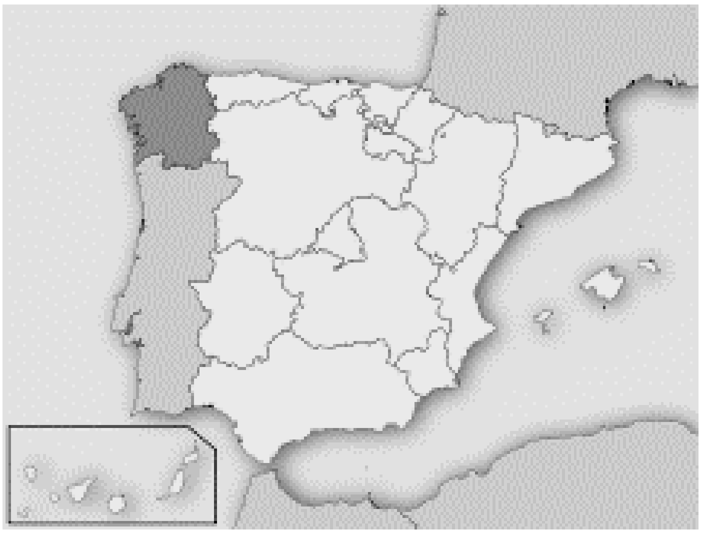

Figure 2. Geographical location of Galicia in the Iberian Peninsula (darker color). Source: National Geographic Institute (www.ign.es).

Indications obtained in the diagram are indicative, and not exclusive. The designer has information of systems that are effective in that place and in the analyzed time. It is from that information that the designer makes the right decisions. Usually, it is advisable to adopt combined measures that allow the best use of the equipment installed in different climatic situations. This leads to true reductions in energy consumption, in addition to the optimization of the consumption of conventional air conditioning equipment to be installed.

It should also be kept in mind that the adoption of corrective strategies for conditions considered insufficient, favors and reduces the use of conventional systems. Thus, if conventional heating is needed, good passive behavior will decrease the amount of energy spent on it. (Da Casa, 2000).

The problem arises when in order to apply this tool to the design process, the precondition is to have weather data corresponding to the location of the building to integrate them into the Givoni diagram and, thus, to know the bioclimatic strategies necessary to correct discomfort parameters. The most common difficulty is precisely obtaining specific location information that is reliable. In many cases it does not exist, which forces complex research processes (Corral, García and Romero, 2018); in other cases, climate data files for simulation are very general and simplified (in order to facilitate their management), without taking into account specific factors such as local overheating or microclimates, nor the effects of climate change (Luciani, Velasco and Hudson, 2018).

In short, the difficulty of using this tool globally, in any territory, to achieve the benefits of sustainable design is presented. Given this, and as starting point for the investigation, the need to answer the following questions is considered: Is it possible to have generalizable climatological data for immediate use? Is it possible to generate an application model from Givoni diagrams? Is it possible to extract from them a basic interpretation of a territorial nature? And, most importantly, is it possible to map all this?

Obtaining answers to these questions is the basis of the objective of this research, which proposes to develop an optimal methodology to develop a "regional bioclimatic cartography" of a specific territory, usable by any technician in the design of buildings, where to have the necessary information to adopt the most appropriate criteria and strategies, based on Givoni bioclimatic chart.

Among the studies related to the subject, we can mention those that address the cartographic representation of bioclimates (Marco, Sariñena, López, MS and López, ML, 2016) or of parameters, such as solar radiation (Díaz, Montero and Mazorra-Aguiar , 2018). There are also some attempts to graph the climatic zoning reference of the Technical Building Code of Spain. There is no reference to the generation of specific cartographies referring to bioclimatic design strategies, beyond a methodological proposal set forth by Da Casa (2000).

The development and application of these strategies facilitates the achievement of SDG, as well as that of all energy efficiency regulations, both those of consumption reduction, and those of increasing the optimization of buildings from their own design. Having this new tool (using the available resources, without having to make an investment, in the case of a public initiative), generates great interest, given the profitability of its approach and its high potential for benefits of a particular territory.

METHODOLOGY

In the investigation process a clear, particular and complete methodology has been established for the elaboration of this type of cartography. In order to verify its feasibility, an example applied to a specific territory was used as a validation system, as a pilot experience. The selected territory was the Autonomous Community of Galicia, in Spain (Figure 2).

In this context, four main phases are established:

- Phase I. Obtaining updated climate information available from the field of study.
- Phase II. Analysis of climatological data.
- Phase III. Implementation of stations and monthly

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data according to Givoni bioclimatic strategies. Start of the cartography process.
- Phase IV. Zoning, and establishment of "maps" of bioclimatic strategies of Givoni, on a monthly basis.

Next, each of these stages is deepened.

PHASE I. OBTAINING UPDATED CLIMATE INFORMATION AVAILABLE FROM THE FIELD OF STUDY.

To obtain specific climatic data from the study area, a network of meteorological observatories was available with the required data (at least, average, maximum and minimum temperature, and average, maximum and minimum relative humidity). The established source of information was the network of meteorological observatories of Xunta de Galicia (www.meteogalicia.es), which has a total of 101 observatories distributed throughout its geography (Figure 3).

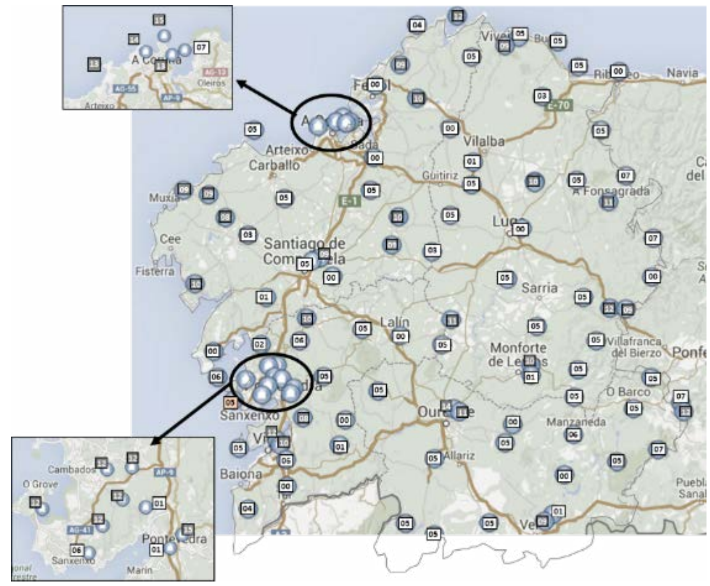

Figure 3. Meteorological stations available from Galicia with date of implementation. Source: Made by the authors based on images extracted from www.meteogalicia.es.

Regarding the minimum period of meteorological data to be collected, it was suggested that this should be sufficient to be referents of the real climate (usually considered 30 years). However, the extension and digitalization of the observatories does not allow such amount to be reached in most cases, which must be taken into account.

To this we must add the potential effect of the current climate change situation, in which the existence of a slight increase in temperature can be accepted as a model (Solanki, Schüssler and Fligge, 2000; Solanki, Usoskin, Kromer, Schüssler and Beer, 2004), especially in winter, and a shift in winter rainfall towards spring, which leads to an increase in oceanity and temperance (not a tropicalization). It affects existing facilities in buildings (Sánchez, Rubio, Marrero, Guevara and Canivell, 2017), as well as other areas (Enríquez, Díaz, Martín and Santos, 2017). This directly affects the application of passive design strategies (Rubio, 2015).

For all the above, it is estimated as acceptable reference a time range around 15 years (representative period of the change). In cases where shorter periods were available, the data were checked in terms of their consistency with the rest of the observatories and they were used in a complementary manner.

In the case of Galicia, the first implementation observatories are from 2000, which implies a period of more than 15 years. In addition, all the observatories consulted have the precise data for the application of the methodology considered in this work.

Thus, 55 observatories distributed homogeneously in the territory were selected, giving priority to older ones. Such selection was made in two phases: 33 observatories in the first one and another 22 in the second one (Table 1). Data of climatic parameters necessary for the elaboration of the bioclimatic chart of Givoni of the entire available period of each observatory were collected on a monthly basis, that is, monthly data on maximum temperature, minimum temperature, average maximum temperature, and average of the minimum, as well as data of the average, maximum and minimum relative humidity.

In order for the geographical distribution of observatories to be consulted to be homogeneous, the selection process was carried out, as already indicated, in two phases: in the first, the highest priority (33 observatories) were chosen, and the second was complemented with 22 other observatories, in order to have as complete coverage as possible of the territory of analysis.

In order to verify if the completeness of the study was valid, with 55 observatories tested, it is worth mentioning that, in 2010, the "Technical guide of external climatic conditions of the project", prepared by the Spanish Technical Association of Air Conditioning and Refrigeration (ATECYR, by its initials in Spanish) for the Institute for Diversification and Energy Saving (IDEA, by its initials in Spanish), is based on data from only 6 Meteorological Stations to determine the climate in Galicia. The objective of this study was to promote efficiency in the final use of energy in buildings. From that background, the number of study points is validated.

OBSERVATORIOS PRINCIPALES CONSULTADOS (1ª fase)					OBSERVATORIOS CONSULTADOS en 2ª fase				
Nº clave	Denominación	Provincia	Municipio	Año implantación	Nº clave	Denominación	Provincia	Municipio	Año implantación
1	Castro Vicaludo	Pontevedra	Oia	2004	A	A Pontenova	Lugo	A Pontenova	2005
2	Monte Aloia	Pontevedra	Tui	2000	B	O Xipro	Lugo	A Fonsagrada	2007
3	Queimadelos	Pontevedra	Mondariz	2001	C	Ventosa	Lugo	Navia de Suarna	2007
4	Entrimo	Ourense	Entrimo	2005	D	Caldas de Reis	Pontevedra	Caldas de Reis	2006
5	Gandarela	Ourense	Celanova	2005	E	Pereira	Pontevedra	Forcarei	2005
6	Baltar	Ourense	Baltar	2005	F	Mouriscade	Pontevedra	Lalín	2000
7	O Invernadeiro	Ourense	Vilariño de Conso	2000	G	Ourense	Ourense	Ourense	2011
8	Xares	Ourense	A Veiga	2007	H	Marroxo	Lugo	Monforte	2001
9	Lourizán	Pontevedra	Pontevedra	2001	I	Serra do Eixe	Ourense	O Barco de Valdeorras	2005
10	Amiudal	Ourense	Avión	2005	J	Cabeza de Manzaneda	Ourense	Manzaneda	2006
11	Alto do Rodicio	Ourense	Maceda	2000	K	Viana do Bolo	Ourense	Viana do bolo	2005
12	San Xoán de Río	Ourense	San Xoán de Río	2005	L	Fornelos de Montes	Pontevedra	Fornelos de monte	2000
13	As Petarelas	Ourense	Rubias	2005	M	Penedo do Galo	Lugo	Viveiro	2005
14	Corrubedo	A Coruña	Ribeira	2000	N	Portomarín	Lugo	Portomarín	2005
15	Muralla	A Coruña	Lousame	2001	O	Abradelo	Lugo	Samos	2005
16	Sergude	A Coruña	Boqueixon	2000	P	Verín-Vilamaior	Ourense	Verin	2001
17	Serra do Faro	Pontevedra	Rodeiro	2005	Q	Corón	Pontevedra	Vilanova de Arousa	2002
18	Bóveda	Lugo	Bóveda	2005	R	Rebordelo	Pontevedra	Cotobade	2005
19	Courel	Lugo	Folgoso	2005	S	Ons	Pontevedra	Bueu	2005
20	Fontecada	A Coruña	Santa Comba	2003	T	Illas Cíes	Pontevedra	Vigo	2005
21	Río do Sol	A Coruña	Coristanco	2005	U	Camariñas	A Coruña	Camariñas	2009
22	Melide	A Coruña	Melide	2003	V	Lira	A Coruña	Carnota	2010
23	Campus Lugo	Lugo	Lugo	2000					
24	Ancares	Lugo	Cervantes	2000					
25	Malpica	A Coruña	Malpica	2005					
26	Mabegondo	A Coruña	Abegondo	2000					
27	Guitiriz	Lugo	Guitiriz	2000					
28	Pol	Lugo	Pol	2005					
29	CIS Ferrol	A Coruña	Ferrol	2000					
30	Punta Candieira	A Coruña	Cedeira	2004					
31	Serra da Faladoira	A Coruña	Ortigueira	2005					
32	Fragavella	Lugo	Abadín	2003					
33	Pedro Murias	Lugo	Ribadeo	2000					

Table 1. List of observatories selected in the study (the year of implementation is indicated). Source: Made by the authors.

PHASE II. ANALYSIS OF CLIMATOLOGICAL DATA

Once all the climatological information was collected, it was considered as the first step to proceed to the homogenization of data obtained from each observatory, according to existing models (Arava, 2014; Cartaya, Zurita and Montalvo, 2016). In this way, individualized tables of each of the observatories were acquired with monthly data (throughout the available period) of maximum and minimum temperature, average maximum and minimum, and relative average, maximum and minimum humidity. This information allowed the analysis of its evolution and the comparative analysis with extreme temperatures. It should be noted that data that responded to situations of equipment failures or deficiencies in the acquisition of these were filtered.

The average data per month of each parameter were entered in the Givoni climate graph, and with the result, the bioclimatic strategies were established on a monthly basis, both for cooling and heating in the required months.

As it is known, Givoni strategies for heating are progressive as the temperature data decreases. This makes possible to use spreadsheets as a tool to present the resulting monthly data, being able to define the limit heating strategy that allows achieve comfort, for each month and in each zone.

With respect to refrigeration strategies, the application is not as direct, since strategies overlap, and its evolution is not as clear as in terms of heating, depending not only on the variation of the temperature, but on the relationship with environmental relative humidity. In this type of strategies, the direct application of Givoni diagram is required to establish results. It is necessary to see that in most of the occasions several strategies will be available, which can even be adopted simultaneously (Guzmán, Cano and Roset, 2019).

With the data obtained, tables and diagrams corresponding to each observatory were prepared, in which the type of strategy required to achieve comfort conditions in each month, corresponding to heating and cooling independently, was indicated.

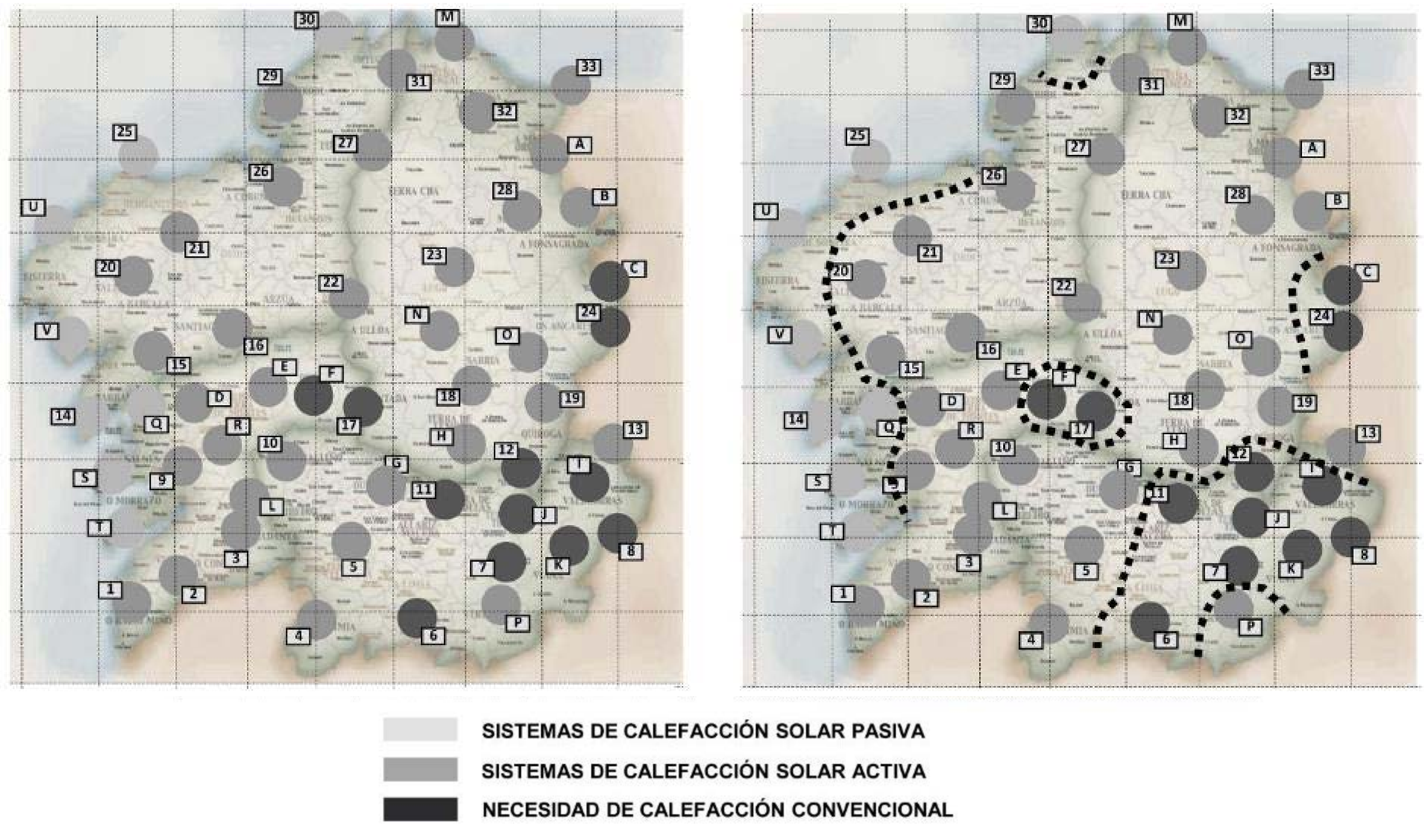

Figure 4. Illustrative example of the initial cartography process corresponding to heating needs of the month of February. Source. Made by authors.

PHASE III. IMPLEMENTATION OF STATIONS AND MONTHLY DATA ACCORDING TO GIVONI BIOCLIMATIC STRATEGIES. START OF THE CARTOGRAPHY PROCESS.

The first step of this phase was the transfer the territory into a map, of the data obtained individually in each observatory. It was captured graphically with color code according to the different strategy necessary for each month in the geographical location of each observatory. In this way, one map was available per month, with all the points selected and coded. Maps for heating and cooling strategies were independently produced.

The second step was to carry out a first analysis in order to verify the existence of uniqueness zones by contrast between results. Complementary analyzes of new observatories were carried out to complement the information and to better define the complexity of boundary zones. Then, the existence of areas of similar behavior could be observed.

In the third step of this phase, the zonal grouping of observatories was carried out whose data imply the use of similar design strategies. Initial limits of each of the territorial areas that had a similar behavior were established graphically.

It is good to point out, as illustration Figure 4 shows, on the left, a positioning of data and, on the right, the first zonal delimitation.

PHASE IV. ZONING AND ESTABLISHMENT OF "MAPS" OF BIOCLIMATIC STRATEGIES OF GIVONI, ON A MONTHLY BASIS.

Once the first outline of monthly maps with the results in the form of data points was established, results in the delimitation between areas of different characterization were analyzed. It was possible to observe the divergences or disagreements, and the areas of doubtful delimitation, or areas where some initially inconsistent behavior was observed.

At that time, the need to expand the number of observatories to be studied was determined, incorporating those indicated in Table 1, as the 2nd phase. In cases where reliable data from an observatory in that area were not available, interpolation was carried out, based on the effective distance and taking into account the difference in altitude and latitude between observatories. In some specific areas the orographic factor and the local wind regime were introduced.

After modifying and adjusting the initial delimitations, the zoning mapping was obtained, on a monthly basis,

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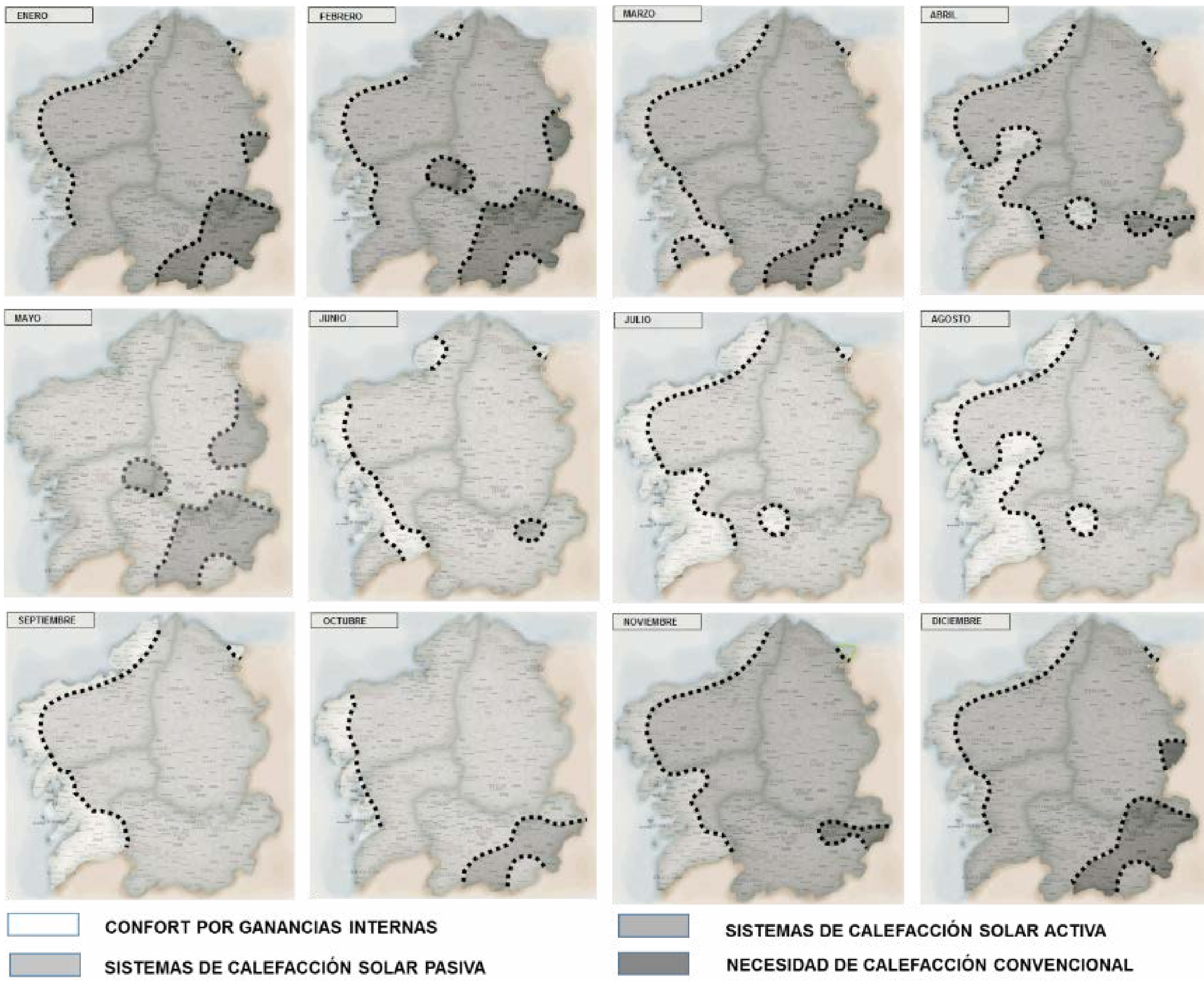

Figure 5. Cartography of bioclimatic strategies for heating in Galicia for each month of the year, according to Givoni. Source: Made by the authors.

of heating strategies and those required for cooling (independently), according to Givoni, with a view to achieving thermal comfort in the studied territory.

Regarding heating strategies, the work generated 12 maps, one per month, since the analysis of the data showed the need to adopt heating strategies throughout the year. Thus, in each month the differentiable zones with different coding were indicated.

The consideration of extreme situations was not taken into account at this stage, notwithstanding that this may be included in subsequent studies. However, such situations should not be considered as the basis of the design, since they would involve excessive oversizing that could generate irregular situations.

Regarding refrigeration strategies, it was in a similar way, showing maps in each of the months in which this type of needs were presented. For the purpose of the investigation, it was proposed to establish as many groups of strategies as they were, according to overlaps of the distribution of the Givoni diagram itself.

It was decided to consider the extreme situations in the case of refrigeration, since these data could be useful as a complement for the information of average parameters, insofar they give indications of extreme states of discomfort.

RESULTS AND DISCUSSION

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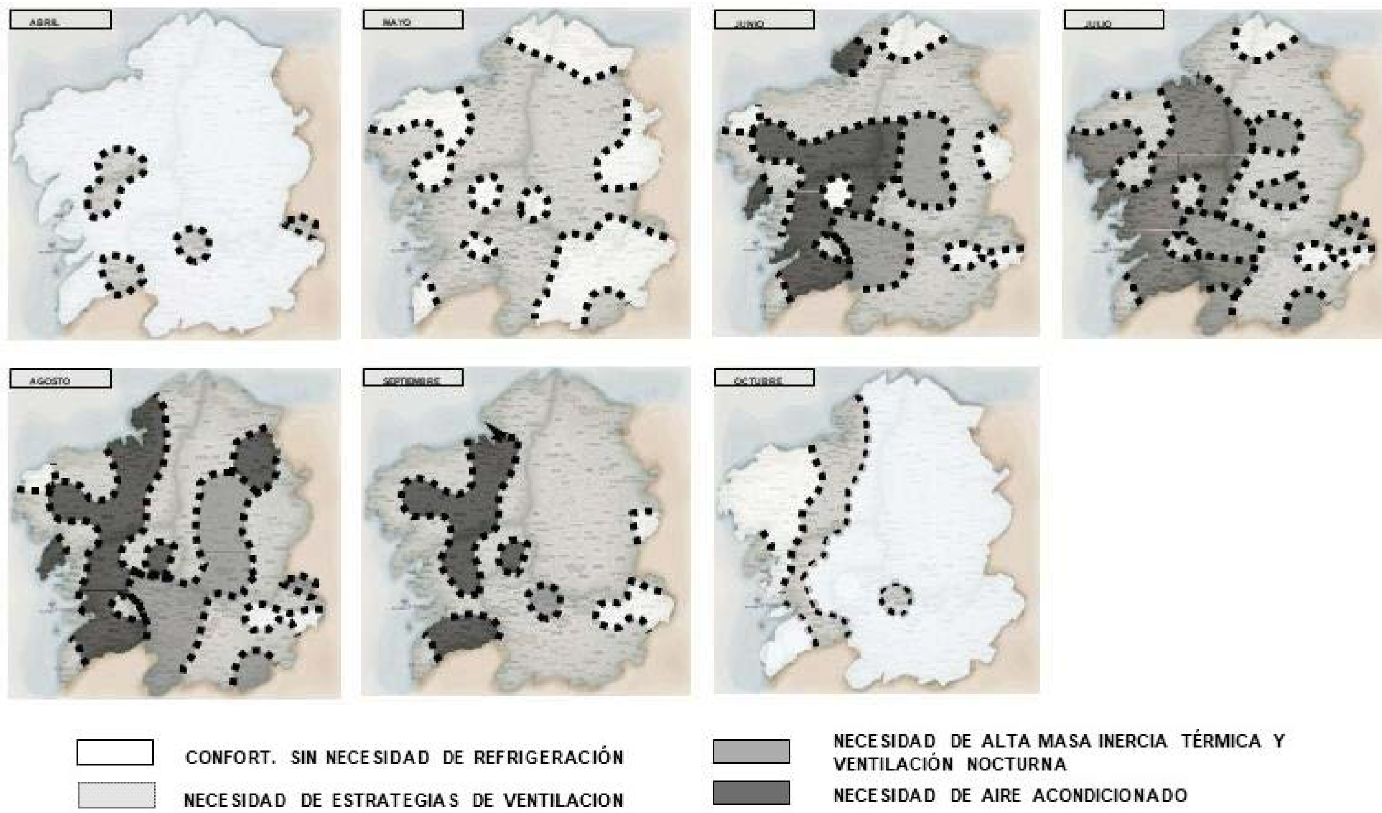

Figure 6. Cartography of bioclimatic strategies for refrigeration in Galicia for maximum temperature from April to October according to Givoni. Source: Made by the authors.

As a result of the application of the proposed methodology, the viability of mapping the needs of air conditioning strategies of a territory was verified. Indeed, 12 maps were obtained, one per month, for heating strategies (Figure 5).

In the case of refrigeration strategies, when applying the data of temperature (maximum and minimum) and average relative humidity (maximum and minimum), a particular circumstance was presented, and it is usual that several strategies are feasible, which can be used individually or simultaneously. But the analysis of the evolution of these strategies was not as clear here as those corresponding to the heating requirements, mainly due to the non-progressive nature of the strategies in the Givoni diagram. This complicated the coding, as there was a greater diversification of points. However, it was proved in practice that in the end diversification is not so wide for each climate.

On the other hand, it was observed that only in 5 dispersed observatories any need for refrigeration is indicated in any month, leaving practically the entire territory in a state of comfort (remember that with the average monthly data).

Given this uniqueness, it was considered interesting to know the mapping of the refrigeration needs in a situation of maximum temperatures, so that the information on the process of adopting bioclimatic strategies in the design could be complemented. When applying the method in these circumstances, refrigeration strategies were dated from April to October, obtaining 7 maps (Figure 6).

Given these results, it is pertinent to present the discussion carried out, which focused on answering the questions related to three main aspects: the reliability of the result obtained, the applicability of the presented cartography, and the ability to extrapolate this methodology to other territories.

DISCUSSION POINT 1: RELIABILITY OF THE RESULT OBTAINED.

When answering the question "Is the information obtained reliable?" It becomes essential to think of the definition of "reliability" itself. If by such term is understood the degree of consistency, stability and absence of errors in the data and its use, must be based on the origin of the used data. The source of climatic data is of all reliability. It is a network of meteorological observatories of a public administration, Xunta de Galicia of public access in digital form (www.meteogalicia.es). The applied data respond to the reality of each location, which were collected continuously and digitally.

The use of a 15-year data collection period allows for a real climate consideration to be established, taking into

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account the evolution produced and the impact of climate change. Therefore, results based on the use of such data can be considered reliable.

The degree of accuracy of the resulting maps responds to the average nature of the weather parameters used, being adjusted for any of the applications for which they can be used. The adjustment made in the delimitation between zones responds to this character with the interpolation between observatories, but taking into account the effective distance between them, the difference in altitude, and even the intermediate orography of the area. In this way, it can be considered to have obtained a balanced and reliable accuracy.

However, if reliability is understood as the "probability of a good functioning of something" (definition of the Royal Spanish Academy), it should be indicated that the consistency check of the maps obtained has been performed, with the climatic delimitation of the Spanish Regulations of the Technical Building Code (Da Casa, Echeverría y Celis, 2017), with a positive result. However, it is clear that each of these zoning responds to different objectives and that the zoning resulting from the methodology applied, not being limited to "reference climates" of the Spanish Standard, conforms to the local reality, expanding coverage of options for bioclimatic design. Therefore, a reliable result can also be considered from this perspective.

DISCUSSION POINT 2: APPLICABILITY OF THE CARTOGRAPHY PRESENTED.

A second issue to discuss about the result obtained is whether the cartography obtained has any other applicability beyond reflecting the design strategies necessary to achieve comfort each month, according to Givoni. Through the analysis carried out in the research process, several applications of great potential have been evidenced.

The first of them is to consider this cartography as a bioclimatic design manual of the mapped region. Any technician or promoter, with the location of the territory on the map, directly obtains the information related to the design strategies necessary to adopt in order to achieve comfort in each of the months. All this, directly, without having to search and interpret the specific climatic data (in many territories this search is very complex for a particular technician).

With the determination of the strategies revealed on the maps, together with the specific conditions of the environment, the designer can establish his own design criteria, appropriate to the territory, the project or the requirements of the use or of the developer himself. Thus, the emergence of efficient and optimized design proposals is encouraged.

A second application consists of the knowledge of the evolution of the needs of the own strategies in the own territory. By observing all the maps together, you can see the evolution of the areas corresponding to each strategy throughout the year.

From the individual analysis by strategies, in the case applied, it is clear which areas are in comfort, not requiring any strategy even in a situation of limit temperature. It can also be noted that, in more than half of the territory, it would not be necessary to have air conditioning systems at any time of the year.

From the analysis of the evolution of strategies in the year, the possibility of generating an annual climatic zoning is determined, adjusted to the physical reality of each territory (Da Casa et al., 2017), and thereby establish coherence with the applicable regulations (if applicable, as in Spain, with the Technical Building Code). The areas of specific singularity can be located, which would allow particular adjustments to the regulations to avoid the appearance of anomalous behaviors, as they do not conform to the general regulatory characteristics.

A third application is its configuration as a tool of great potential for territory research. On the one hand, it allows comparative analysis of the areas obtained, but also of other factors, such as those dependent on human intervention, among which we can mention:

- The location of human population.
- The territorial communication channels.
- The popular and vernacular architecture of the territory
- The study of the needs according to the uses of the territory.

On the other hand, it allows investigating, through comparative analysis, the relationship with the conditions imposed by the characteristics of the territory. Thus, for example, this method opens doors to the study of:

- Geology of the territory; with the objective of having knowledge of materials of each defined area and its possible application in the construction framework, as well as conditions that the nature of land imposes, affecting directly the local microclimate.
- The orographic, topographic and morphological aspects, given conditions of variability between coast and high mountains, and between different altitudes.
- Hydrology, within this field of study, since it influences the degree of environmental humidity. The presence of water (surface or underground) may involve a sensitive variation of the strategies.
- The vegetation of the territory and its variation. The modifications that the vegetation incorporates into the local microclimate are determined by its size and type. Among them, the main ones will be the contribution of humidity, and a relative climatic smoothness, as well as the ability to provide shadows and wind protection.
- The incidence of wind in the territory. Variations of slope, or mountains aspect, and existing obstructions can alter

the parameters obtained in meteorological observatories. Factors that affect the changes of speed, direction and frequency of the prevailing winds affect the needs of ventilation, wind protection or the combination of both, necessary to achieve comfort.

- The incidence of solar radiation and the incidence values per month. It is possible to determine the collection capacity in the less favorable months and the need for its protection in the months that record maximum values.

DISCUSSION POINT 3: ABILITY TO EXTRAPOLATE THE METHODOLOGY USED TO OTHER TERRITORIES.

The last point of discussion raised asks whether the proposed methodology has the capacity to be extrapolated in order to be applied to another territory. Well, after the development of the investigation you can deduce its easy application to any territory, regardless of its extension.

For a correct use of this methodology it is, however, essential to be aware of its limitations. You have to keep in mind that:

- The first condition is to have sufficient meteorological observatories with the required data, with a homogeneous geographical distribution. The distant geographical arrangement between observatories may obviate some intermediate situations. The greater the number of observatories, the accuracy of the resulting cartography improves.
- When using climatic data that express monthly averages, extreme situations are not contemplated (these could be recorded, however, at the stage of data preparation). Information obtained as an acting instruction cannot be treated. The cartography thus obtained provides an idea of order and magnitude of the strategies in the geographical area of study, being able to differentiate the general behavior of various identified areas.
- The limits of the zones obtained, by constituting data clusters, may have a certain degree of inaccuracy. In case of doubt, a more in-depth analysis of the characteristics of the environment should be made.

They are aspects that are proposed to improve the progression of the research project that is the result of this work. In that sense, it is worth noting that, for public administrations of each territory, the cost of obtaining this data is minimal, since access to such information is generally available. These benefits are multiplied, in the case of territories where there is no specific regulation for energy efficiency or where there are no reference climates.

The cartography presented facilitates, finally, its potential application as a bioclimatic design manual, for which a final recommendation is worth. The process would begin with the location of the territory on the map. The information related to design strategies to be adopted is thus obtained directly to achieve comfort in each of the months of the year. Results obtained must be considered as an approximation to the real situation, so it must be the designer who establishes the design criteria and makes the decisions he deems appropriate, always taking into account the rest of the parameters (the territory, the object of the project, or the requirements of the use or of the developer itself).

CONCLUSIONS

The main contribution of the research carried out and exposed here is the methodology to elaborate a regional cartography, whose purpose is to apply bioclimatic strategies to achieve adequate levels of thermal comfort, following the bioclimatic chart of Givoni.

In the development of the work, the methodology in question has been validated through its application to a specific territory in Spain (the Autonomous Community of Galicia), as a result of obtaining a set of monthly maps, where necessary intervention strategies are established, under bioclimatic parameters, which must be adopted in order to achieve thermal comfort in buildings, in such territory and in such period.

The mapping produced in this way becomes a powerful tool for bioclimatic design in the studied territory. Consequently, the possibilities of developing bioclimatic architecture are evident. The tool, in effect, constitutes an open field full of possibilities to be inserted in the usual projection of architectural design systems. The development and application of these strategies contributes to achieving SDG, as well as all energy efficiency regulations, both in terms of reducing consumption and increasing the thermal optimization of buildings from their own design.

The systematics described here is likely to be applied to any territory deemed necessary, beyond the extent of it. With this, it is also possible to have a tool to increase knowledge of the mapped territory itself.

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OPTIMAL COST AND THE ECONOMIC VIABILITY OF ENERGY-EFFICIENT HOUSING RENOVATION IN SPAIN

COSTE ÓPTIMO Y VIABILIDAD ECONÓMICA DE LA REHABILITACIÓN ENERGÉTICA DE VIVIENDAS EN ESPAÑA

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RESUMEN

Las exigencias europeas de ahorro energético en edificación establecen las directrices para que cada país miembro defina su propia metodología de coste óptimo, basada en términos de coste-eficacia, tanto para obra nueva como para rehabilitación. En el caso de España, actualmente esa metodología se encuentra en fase de desarrollo, por lo que el presente estudio aplica las directrices europeas y plantea diferentes medidas de rehabilitación pasivas en la envolvente para dos tipologías de edificios representativos en dicho país, un edificio entre medianeras en casco histórico y otro bloque de viviendas aislado, situados en cinco zonas climáticas diferentes. El trabajo relaciona la demanda y consumo energético (kW•h/m2 año) con el coste global (€) para diferentes propuestas, obteniendo los valores de coste óptimo y períodos de amortización. Se propone, además, el indicador de "coste30", como el coste adecuado para conseguir amortizaciones inferiores a 30 años, y se amplía el análisis incorporando el salario mínimo interprofesional a la inversión. Los resultados concluyen que la metodología de coste óptimo permite obtener valores adecuados y que, en ese marco, existe un abanico de intervenciones válidas que dependen principalmente de la tipología, la zona climática y los costes de inversión.

Palabras clave

desempeño térmico, renovación arquitectónica, ahorro de energía, costes de construcción.

ABSTRACT

The European requirements for energy savings in buildings set the guidelines by which each member country establishes their own optimal cost methodology with respect to cost-effectiveness, both in new buildings and renovations. In the case of Spain, this methodology is currently in the development phase. Therefore, this study applies the European guidelines and proposes different passive renovation measures in envelopes for representative building typologies in Spain: a building between party walls in a historic district and an apartment building, located in five different climatic zones. The study relates energy consumption and demand (kW•h/m2 year) and global cost (€) for different proposals, and determines optimal cost values and amortization periods. In addition, it proposes the cost30 indicator as the appropriate cost that enables amortization periods of less than 30 years; furthermore, the analysis is broadened by considering minimum wage in the investment. The results conclude that suitable values may be obtained with the optimal cost methodology, and that there are a variety of different valid renovation measures that depend mainly on typology, climatic zone and investment costs.

Keywords

thermal performance, building renovation, energy savings, construction costs.

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INTRODUCTION

According to the recommendations of the European Community, it is currently crucial to reduce energy consumption in all sectors, with the building sector being responsible for 40% of total consumption. The bases for this reduction are laid on Directive 2010/31/EU (European Union, 2010), which develops new approaches and requirements in the area of energy efficiency in buildings and which have been transposed to the regulations of Spain (Building Technical Code, 2017).

Regarding the rehabilitation of buildings, according to modifications of the European Union (2019), 35% of the buildings are over 50 years old and 75% of the stock is inefficient, with a renovation percentage of less than 1.2%, so that rehabilitation has great potential for energy improvement, which can mean reducing consumption and CO_2 emissions around 5%.

The two main lines to address the energy problem of building in Europe are the commitment to standards of nearly zero energy consumption buildings (Nearly zero-energy buildings, nZEB) and rehabilitation. In the latter case, the main problem is the physical limitation of an existing building, and the measures to be adopted will differ from those proposed in new buildings, so solutions must be "technically, functionally and economically feasible", according to Article 7 of the Directive (European Union, 2010).

But in the energy equation it is necessary to include the economic parameter that is key to the economic viability of interventions, forcing to define among all the possible options those most suitable to achieve an optimal balance between investments made and energy costs saved up to depreciation.

For this reason, the European Community has established the need for each Member State to define its own methodological framework (under development in most countries) that allows calculating and comparing the profitability optimum, established in Delegated Regulation RD 244/2012 and in its explanatory guidelines (European Union, 2012b).

The methodology to be applied must be particularized and will depend on each Member State:

> "Despite a common methodology to calculate cost optimal levels, the results are not fully comparable between countries, as member states are free, for example, to choose the macroeconomic or financial perspective when calculating cost optimal values or have different national rules to calculate energy performance of buildings" (ECOFYS and EURIMA, 2015).

With a methodology not yet approved in Spain according to RD 244/2012 and the UNE-EN 15459: 2008 standard (AENOR-CEN, 2008), the only official reference (Ministry of Development, 2013) establishes a comparative analysis of different measures and measurement packages in existing and newly constructed buildings, for different climatic zones. Given the current absence of regulation and increasing energy requirements in the regulations, towards NZEB standards, the analysis of the optimal cost is considered as a key aspect on which the present study is raised.

There are other works that have already addressed the issue and that analyze a wide spectrum of buildings, among them the following stand out: the Episcope Project (2016); the Concerted Action project (CA-EPBD, 2016) or the guides published by ECOFYS in collaboration with the European Insulation Manufacturers Association (EURIMA) (2015); the TABULA project (2012), which establishes common criteria for classifying the stock of buildings according to age, size and climatic zone, in addition to other energy parameters.

Under the same methodology, other studies analyze a wide spectrum of building typologies, for representative climates of Europe and even consider buildings of almost null consumption NZEB (Zangheri, Armani, Pietrobon and Pagliano, 2018), in Italy (Corrado, Ballarini and Paduos, 2014) or including other uses such as offices (Arumägi, Simson, Kuusk, Kalamees and Kurnitski, 2017) or educational (Niemelä, Kosonen and Jokisalo, 2016).

Some authors propose different levels defining "mild rehabilitations, shallow renovations" for interventions that achieve energy savings of 32%, or "intense rehabilitations, deep renovations", which reach 80% (ECOFYS and EURIMA, 2012), referred to in other investigations as "Basic rehabilitations" or "plus" (Pérez, Calama and Flores, 2016).

Social aspects have also been incorporated that value the cost of investment per family (De la Cruz, De la Cruz and Simón, 2018) in mild, moderate or intense levels of investments, depending on the cost in €/housing (Re-Program, 2015), (Luxán, 2017).

There is no official methodology of optimal cost that provides a representative database of residential buildings in different climates in Spain, nor an assessment of the economic impact on families. Based on these deficiencies, the current study is formulated, for passive interventions in the envelope, with the objective of assessing the cost and amortization of different energy rehabilitation proposals in five climatic zones of Spain, in the Autonomous Community of Andalusia, quantifying fundamental parameters of energy demand for heating and cooling together (kW•h/m^2 year) and economic investment (€).

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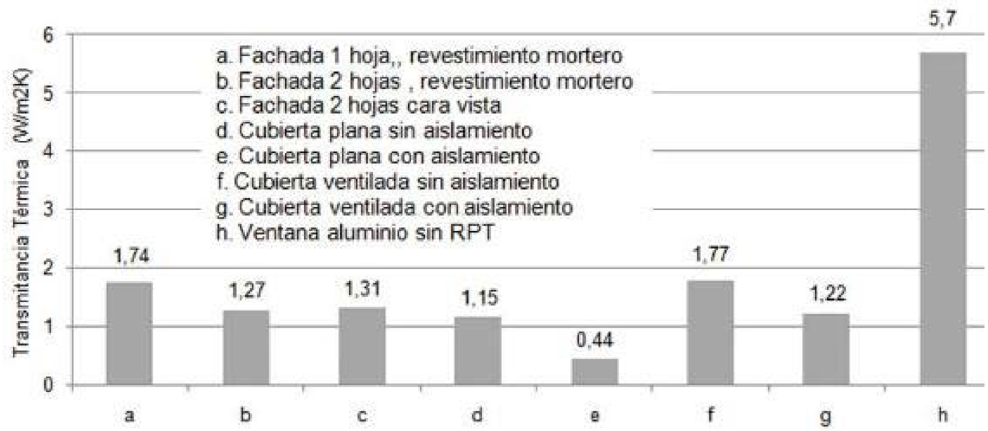

Figure 1. Thermal transmittance values U (W/m2K) in reference buildings.Source: Made by the author.

To achieve this goal, two typologies of residential buildings representative of a large part of the built park are analyzed. One of them is a building between town houses, located in an area of the historic center, and the second, a block building, located in a new residential area.

It is part of the objective to follow the optimal cost guidelines, prioritizing passive interventions in accordance with the global spirit of Directive 2010/31/EU, and incorporate the financial capacity of families including the minimum interprofessional salary.

METHODOLOGY

The methodology used in the study is indicated below:

- Definition of two reference buildings, a building between town houses (EM, by its initials in Spanish) and a block building (EB, by its initials in Spanish), as well as its constructive and geometric conditions, representative of much of the park built in Spain, based on statistical data.

- Definition of five climatic zones of study, according to CTE (2017).

- Definition of passive interventions to be carried out on the envelope, grouped into measures/packages/variants, according to the guidelines of the optimal cost methodology of RD 244/2012.

- Energy calculation, through the use of the dynamic simulation application LIDER-CALENER Unified Tool (HULC) (2017), a tool recognized in Spanish regulations, to obtain values of joint energy demand for heating and cooling, and primary energy consumption (kW•h/m^2 year).

- Economic calculation, through which the overall cost and residual value of each measure/package/variant is obtained. The overall cost is made up of the initial investment according to market prices and construction databases, plus the cost of energy during the useful life. The study is extended by assessing the economic impact per family with respect to the minimum interprofessional salary (SMI, by its initials in Spanish).

- Graphical representation of optimal cost and amortization. The study is extended with the proposal of "cost30", to achieve amortization of less than 30 years.

DEFINITION OF REFERENCE BUILDINGS

To cover the scope of the study, two reference buildings of the built park have been defined, according to statistical publications, which will allow expand the area of knowledge and perform a comparative analysis between both.

Regarding the surface, in Andalusia most of the houses (29.51%) have an area between 76 and 90 m2 (National Statistical Institute [INE], 2019), with a large percentage of brick facades (54, 35%) with mortar coatings (34.99%), passable flat roof and aluminum exterior carpentry (86.25%), (Development Ministry, 2018).

With this constructive characterization, envelope elements of reference cases have been defined, whose resulting thermal transmittance values are shown in Figure 1.

Considering the above parameters, two real reference buildings have been determined, a building between town houses (EM) and a block building (EB) (Figure 2), whose characteristics are summarized in Table 1.

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Figure 2. Reference buildings: town houses building (EM) and block building (EB). Source: Photographs made by the author.

	Description of building	Geometry (Useful surf. /n° homes)	Windows (m^2 / %)	Constructive features U (W/m^2K)
Town houses building (EM)	Years: 1900-1920 Lot: 180m^2 Vol.: 2.250m^3 Facades surf: 111,56m^2 Construct. Surf.: 450m^2	100 m^2 / 2	18,54m^2 / 2,56 %	Brick wall, 1 hoja: U=1,74 Town houses: U=2,33 Flat roof "andaluza": U=1,15 Aluminum window, single glass. U=5,70, g (lot factor)=0,85
Block building (EB)	Years: 1961-1980 Lot: 392,95m^2 Vol.: 19.254,55m^3 Facades surf: 2.732,80m^2 Construct. Surf: 2.841m^2	90 m^2 / 20	771,20m^2 / 18,60 %	Brick wall seen, 2 plates: U=1,31 Flat roof "catalana": U=1,22 Aluminum window, single glass U=5,70, g (lot factor)=0,85

Table 1. Characteristics of reference buildings. Source: Made by the author.

- Building between town houses (EM): located in the historic center, three floors, an exterior facade and an interior yard.
- Block building (EB): residential housing, isolated, twelve floors and four exterior facades.

DEFINITION OF CLIMATE ZONES

In Spain, fifteen climatic zones are defined in CTE (2017), covering a broad spectrum of hot and cold areas and that have generated in the traditional architecture different passive bioclimatic solutions and strategies in their adaptation to the environment, from the use of plant covers (Molina and Fernández-Ans, 2013) to natural ventilation strategies also used in continental temperate climates (Mercado, Esteves, Barea and Filippín, 2018).

The study cases are established for the Community of Andalusia (Spain), which comprises seven types of climate represented in Figure 3; which, in turn, correspond to five climatic zones, in accordance with the climatic zoning established by regulations (CTE, 2017, appendix B), so that the study can be extrapolated to other provinces.

The determination of climatic zones is defined by a letter, corresponding to the winter division, and a number, corresponding to the summer division, according to the following classification:

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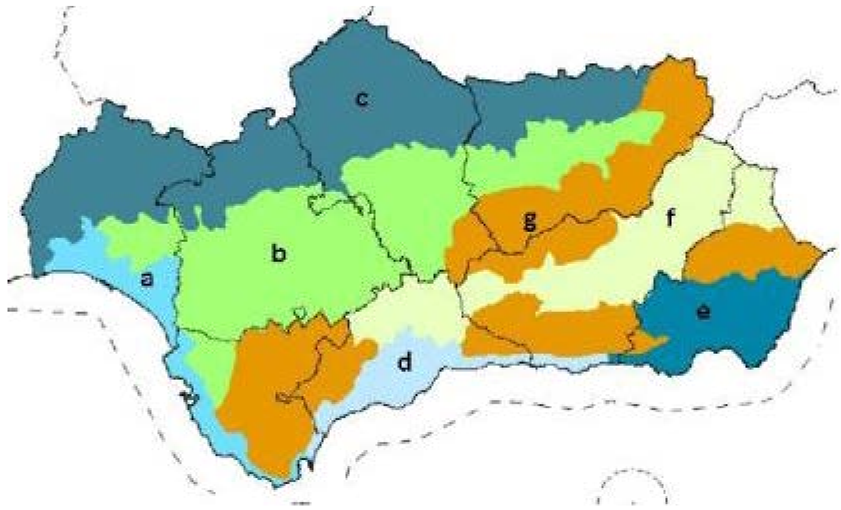

Figure 3. Types of Mediterranean climate in Andalusia: Oceanic (a), Continental (b), Semi-arid (c), Subtropical (d), Sub-desert (e), Continental (f), Mountain (g). Source: Ministry of Environment (2019).

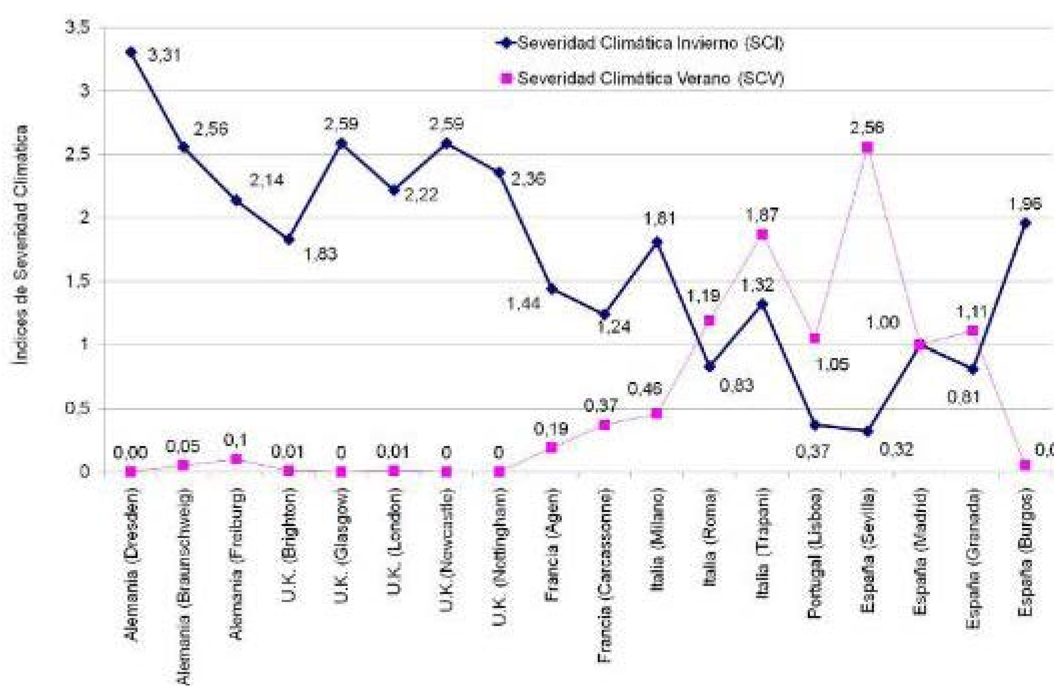

Figure 4. Climate Severity Indices in Europe. Source: Passive-On Project (European Commission, 2007).

- Climatic zone A3: Cádiz-Málaga
- Climatic zone A4: Almería- Huelva
- Climatic zone B4: Córdoba- Sevilla
- Climatic zone C3: Granada
- Climatic zone C4: Jaén

Compared to other European cities, some areas have high rates of climatic severity in summer (SCV) and intermediate levels in winter (SCI), as shown in Figure 4.

DEFINITION OF PASSIVE INTERVENTIONS

At this point, different passive rehabilitation interventions are determined that offer a reduction in the building energy demand, grouped into: measures, packages and variants, in line with Directive 2010/31 /EU and other studies (Suárez and Fragoso, 2016).

The measures are interventions on facades and roofs, inside and outside (SATE, External Thermal Insulation System - by its initials in Spanish) as well as the replacement

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Measures		Variant 1: Individual packages	Variant 2: Total intervention
Exterior facade	5 cm EPS (U =0,52) 5 cm PIR (U =0,42)	Exterior facade (EPS) Interior facade (XPS) Exterior roof (BA) Interior roof (MW) Aluminum window, low glass e PVC window, low glass e	Exterior facade (EPS) + Exterior roof (BA) + PVC window, low glass e
Interior facade	5 cm EPS (U=0,50) 5 cm XPS (U=0,47) 5 cm MW (U=0,53) 5 cm TER (U=0,23) 5 cm PUR (U=0,48)		
Exterior roof	7 cm XPS (U=0,34) 7 cm BA (U=0,47)		
Interior roof	7 cm EPS (U=0,35) 7 cm MW (U=0,37)		
Aluminum carpentry	Al +vidrio (U=2,92) Al +vidrio bajo e (U=1,84)		
PVC carpentry	PVC + glass (U=2,74) PVC + low glass e (U=1,66)		

Table 2. Adopted measures/packages/variants. Source: Made by the author.

Setpoint temperature (°C)	Summer: 25-27 °C. Winter: 17-20 °C
Ventilation	Summer: 4/perf./hour at night (1-8h)
Infiltrations	0,24 perf. /hour for housing blocks
Gaps	Shadow factor 0,7; blinds down 30%.
ACS/Housing Demand	56 liters/day at 60°C
Air conditioning	60% homes: Air/air heat pump 2x1 (EER 2,5; COP 2,7) 40% homes: Air/air heat pump 1x1 (EER 2,5; COP 2,7) + electric heater 2kW thermal (Joule effect)

Table 3. Main calculation parameters considered in HULC. Source: Made by the author.

of windows. In all cases the thermal transmittance limit values have been met (CTE, 2017).

The packages define constructive solutions using various insulators (EPS, expanded polystyrene; PIR, Polyisocyanurate; XPS, extruded polystyrene; PUR, Polyurethane foam; MW, mineral wool).

The variants group different measures and packages, offering several energy rehabilitation options.

As for the thicknesses of insulations, on facades they are defined of 5cm and on roofs of 7cm, composed of concrete tiles with built-in XPS insulation (BA, insulating tiles). The exterior carpentry is made of aluminum with thermal bridge break or PVC, in both cases with insulating glass and low emissive.

Finally, a Variant 1 has been analyzed, composed of several individual measures, and another Variant 2 as a total intervention (Table 2).

ENERGY CALCULATION

The calculation has been carried out with the HULC dynamic simulation application that allows to establish the demands and consumption of primary energy necessary to maintain predefined comfort conditions, according to operational conditions of setpoint temperature, occupation, lighting and ventilation indicated in Appendix C, residential use profiles (CTE, 2017, appendix C).

The main calculation parameters are indicated in Table 3; 60% of the houses have been considered to have a

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A3			Climate zones demand / consumption (kW•h/m2 year)				
			A4	B4	C3	C4	
Variant 1: Individual Packages							
Walls	EM	Exterior facade -EPS	28,37/65,2	38,89/71,9	56,18/91,6	78,72/ 128,3	73,83/ 117,4
		Interior facade-XPS	32,92/74,5	40,22/76,1	58,06/93,4	80,58/ 137,7	76,08/ 114,9
	EB	Exterior facade -EPS	40,27/91,8	51,72/97,7	72,88/120,9	113,03/192,1	100,61/151,9
		Interior facade-XPS	42,01/94,94	53,55/102,8	75,79/125,8	115,95/197,1	101,99/164,2
Roofs	EM	Exterior roof-BA	35,62/80,6	43,86/84,49	61,85/110,5	88,60/ 151,4	82,07/ 132,3
		Interior roof-MW	35,24/79,8	43,32/83,4	61,04/109,1	87,54/ 149,6	81,09/ 130,7
	EB	Exterior roof-BA	47,33/107,1	59,39/114,4	83,76/149,1	130,14/222,4	114,87/185,2
		Interior roof-MW	47,13/106,7	59,15/113,9	83,44/148,5	129,67/221,6	114,45/184,5
Windows	EM	Aluminum window, low e	27,79/62,9	33,41/64,4	47,93/85,6	66,33/ 113,3	63,13/ 101,8
		PVC window, low e	30,16/68,3	36,69/70,7	51,47/91,9	71,03/ 121,4	67,71/ 109,1
	EB	Aluminum window, low e	41,19/93,1	52,45/100,7	74,04/131,8	112,51/191,3	100,02/161,2
		PVC window, low e	40,80/92,2	52,02/99,8	73,42/130,7	111,31/189,2	99,14/ 159,8
Variant 2: Total intervention							
Wall + Roof + Window	EM	Exterior facade-EPS Exterior roof-BA PVC window, low e	28,37/63,8	34,63/57,1	45,22/71,4	54,79/ 83,82	63,66/ 94,6
Wall + Roof + Window	EB	Exterior facade-EPS Exterior roof-BA PVC window, low e	36,18/81,4	46,29/76,4	63,43/100,2	89,48/ 136,9	100,41/148,6

Table 4. Joint demand/Consumption (kWh/m2 year). Town house building (EM), block building (EB). Source: Made by the author.

2x1 multi-zone direct air/air expansion system, and the remaining 40%, a 1x1 compact system, including an electric heater support.

Table 4 shows results of joint demand for heating and cooling, and consumption (kW•h/m^2 year), for the different variants and the five climatic zones.

ECONOMIC CALCULATION

GLOBAL COST

For each proposal a global cost is calculated, sum of the investment, operation and replacement cost, as well as the cost of disposal, according to the European methodology (European Union, 2012a) (Figure 5).

The initial investment costs include the previous demolition and preparation work, materials and the installation (labor, tools, scaffolding, rubble containers), considering the negligible design derivatives. Manufacturer prices (DANOSA, s/f; URSA, s/f) and construction price bases in Spain (ATAYO, s/f) have been taken as reference; COAATGU, 2018; Junta de Andalucía, 2017).

The annual cost includes those due to operation over a period of 30 years, mainly associated with energy costs. Replacement and maintenance costs are considered null.

The cost of energy is quantified with a 59.10% electric mix (€ 0.12/kW•h) and 40.90% from other sources (€ 0.035/kW•h), according to official passing factors of primary energy (Government of Spain, 2016) and the price of kW•h (Institute for Diversification and Energy Saving [IDEA], 2016). The annual increase in energy cost has been estimated at 4%.

RESIDUAL VALUE

It is necessary to consider the residual value in 30 years of the interventions, discounting it from the initial investment cost according to the linear depreciation defined in RD 244/201 (Figure 6).

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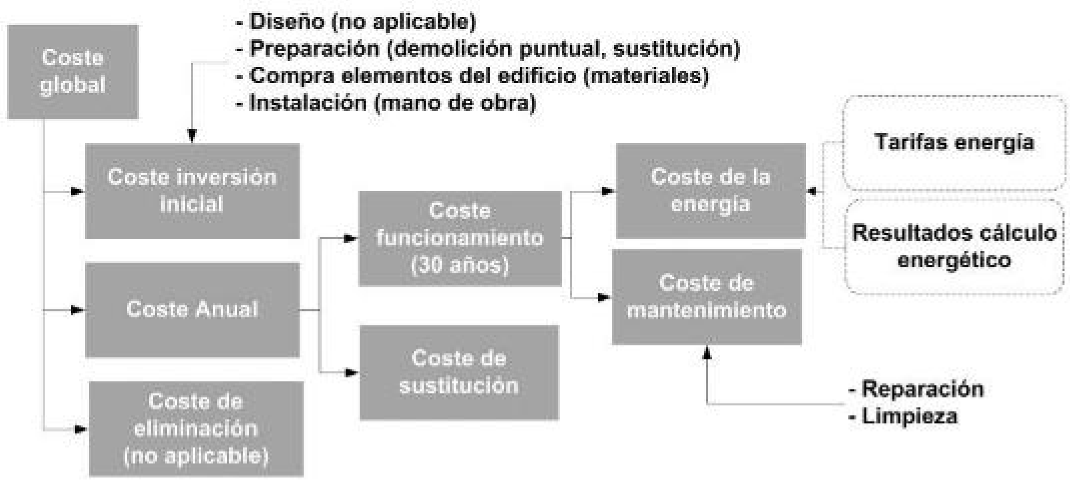


Figure 5. Cost categorization according to the European framework. Source: Guidelines RD 244/2012 (European Union, 2012a).

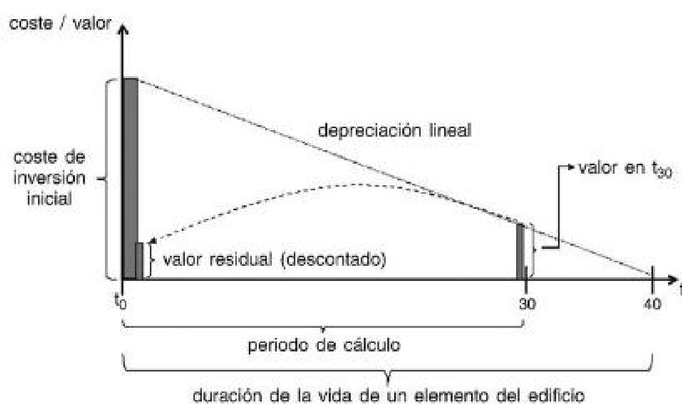
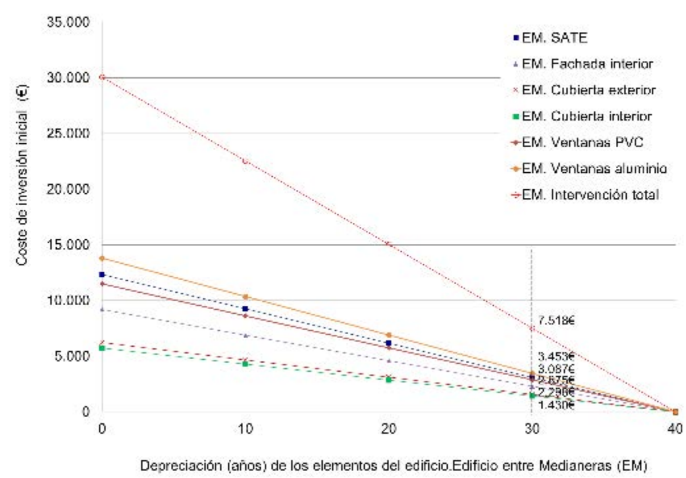


Figure 6. Depreciation of the element of a building. Source: Guidelines RD 244/2012 (European Union, 2012a).



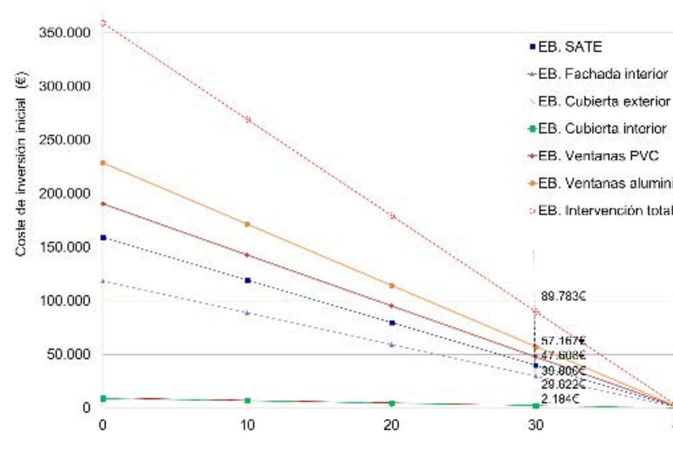


Figure 7. Depreciation and residual value in 30 years. Town houses building (EM). Source: Made by the author.

Figure 8. Depreciation and residual value in 30 years. Building in block (EB). Source: Made by the author.

Considering a maximum depreciation of 100% in 40 years, in 30 years a residual value of 25% is obtained, a limit associated with the useful life of facades; the respective results are indicated in Figures 7 and 8 for Variant 1 (6 individual measurements) and Variant 2 (total intervention), in the two types of the analyzed buildings.

ECONOMIC RESULTS

From the previous results, the global cost value results in 30 years (initial investment + consumption with 4% increase in energy price - residual value) in €/m^2 of constructed area, indicated in Table 5. The initial investment costs are valued in m^2 of each construction solution (facade, roof or window).

The social aspect is incorporated, valuing the economic capacity to address the cost of the initial investment by both housing and family unit, based on the minimum interprofessional salary (SMI), established in Spain at € 900/ month for the year 2019 and considering two families in the

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	Global Cost €/m² constructed		Initial investment €/m² constructive solution	Impact €/m² housing		Cost €/family		N° times SMI	
	EM	EB		EM	EB	EM (2 fam.)	EB (20 fam.)	EM	EB
Variant 1. Individual packages									
Ext. facade - EPS	48,95	149,12	48,92	27,44	56,04	6.170	7.960	9	11
Int. facade- XPS	48,24	143,00	36,41	20,42	41,71	4.600	5.925	7	8
Ext roof. - BA	45,99	128,37	41,48	13,83	3,34	3.110	470	4	1
Int. roof. - MW	44,78	127,64	38,14	12,71	3,07	2.860	440	4	1
Al window	50,81	169,91	296,51	30,69	80,50	6.910	11.430	10	16
PVC window	49,33	158,78	246,93	25,56	67,04	5.750	9.520	8	14
Variant 2. Total intervention									
Ext. facade EPS +Ext. roof BA +PVC window	78,49	191,03	-	66,83	126,43	15.040	17.960	21	26

Table 5. Global cost and investment per family. Town houses building (EM), block building (EB). Source: Made by the author.

building between town houses and twenty families in the block building.

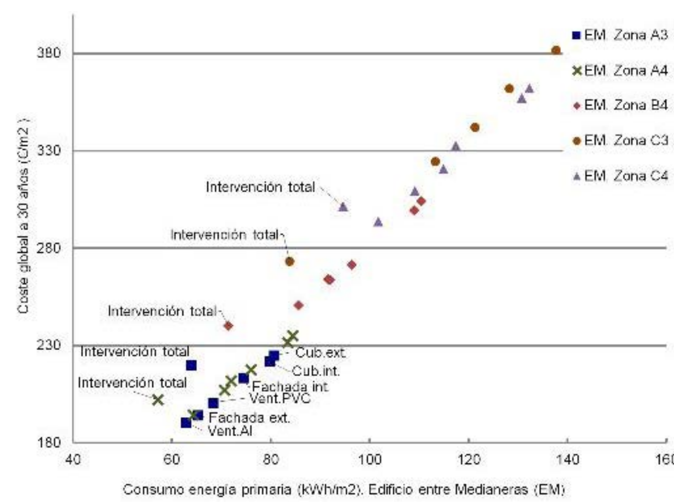
Results indicate that interventions in the building between town houses represent between 4 and 21 times the SMI, and 1 to 26 for the block building. The lowest values correspond to interventions on roofs and the highest for Variant 2 of total intervention.

The cost per family unit allows to define intervention levels according to other publications, which delimit them in light (<€ 2,500/house), moderate (€ 2,500-4,500/house) or intense (>€ 4,500/house) investment, (Re-Program, 2015). Similar studies establish for the Metropolitan Region of Chile three levels of intervention according to family income (Low-Medium-High incomes), with very low percentages of initial investment by families 2%-3%-0%, which are financed by government support and bank loans (García and Croxford, 2015); and other authors consider low-cost solutions for investments of less than € 4,200 /family (Luxán, 2017).

OPTIMAL COST AND AMORTIZATION

The values obtained from the global cost in 30 years are related to the annual consumption (kW•h/m²) calculated in HULC, obtaining the optimal cost represented in Figures 9 and 10. Here is the building between town houses that offers the lowest consumption.

The results allow select the most appropriate optimal cost among the different proposals, so that the values of the x-axis indicate the optimum level of profitability; and for those proposals with similar costs, the one with the lowest use of primary energy will be the one that defines the optimum level.



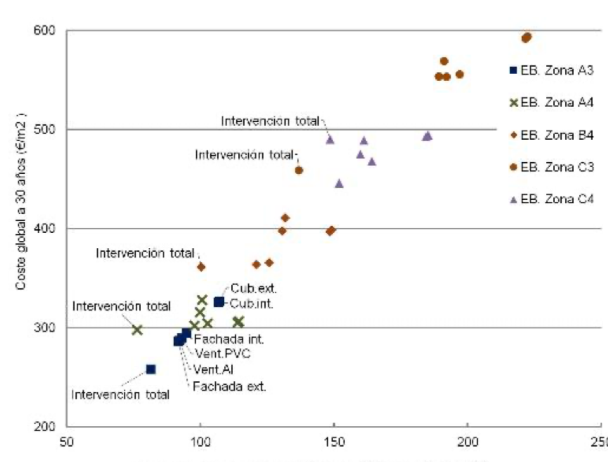


Figure 9: Optimal cost building between town houses (EM). Source: Made by the author.
Figure 10. Optimal cost. Block building (EB). Source: Made by the author.

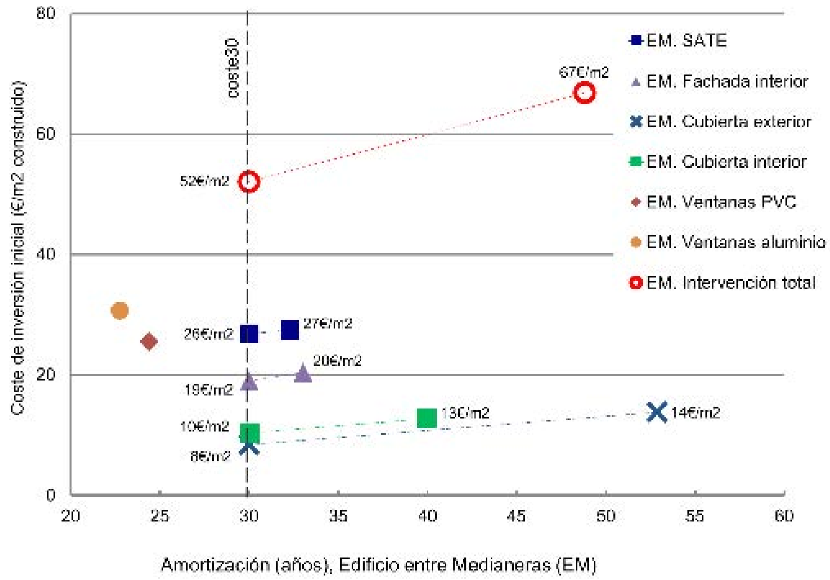


Figure 11. Amortizations (years) and "cost30" (€/m2), average values of the 5 climatic zones. Town houses building (EM). Source: Made by the author.

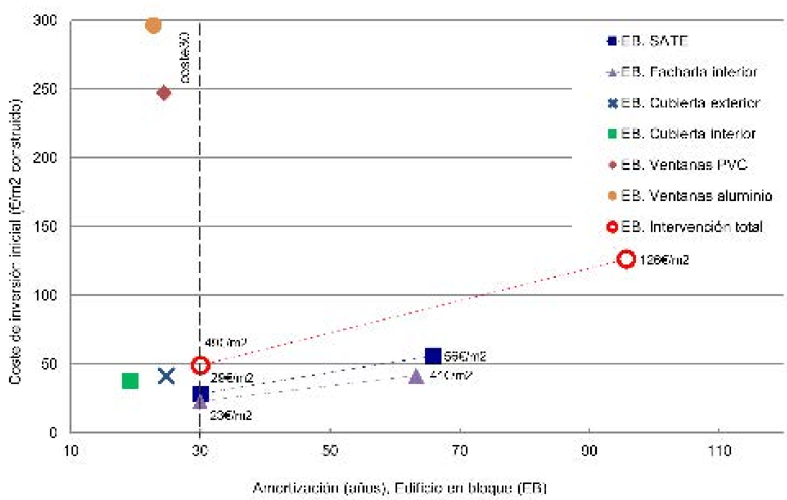


Figure 12. Amortizations (years) and "cost30" (€/m2), average values of the 5 climatic zones. Block Building (EB). Source: Made by the author.

AMORTIZATIONS AND "COST30" PROPOSAL"

Once the optimum cost is determined, amortization periods (years) of each intervention are calculated, dividing the initial investment cost (€) by the energy savings obtained (€/year).

For depreciation over 30 years, the study proposes the value of "cost30", setting the depreciation value and calculating the initial cost. This value is an indicator of how much it would be necessary to lower the initial cost in order to obtain amortizations in a maximum of 30 years.

In order to facilitate the interpretation of results, all values have been calculated with the average values of the five climatic zones. Figures 11 and 12 show the calculated depreciation and the "cost30" values".

It is necessary to indicate that some of the measures already offer amortizations of less than 30 years, such as PVC or aluminum windows, in both models, and roof interventions for block building.

Results indicate that, in the case of the total intervention, it is required to reduce the cost from 67 to € 52/m^2 built in the town houses building, and from € 126 to € 49/m^2 in the block building.

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RESULTS AND DISCUSSION

The optimal cost methodology is based on energy calculation models under standard use conditions, which are still estimates of the real behavior of buildings.

The results of energy demands show great variability depending on the climatic zone: the lowest values occur in zone A3 (Cádiz-Málaga) and the highest in zone C3 (Granada).

It is necessary to disassociate the amortizations with the consumption, since high consumption offers very low returns on investment. Among the calculated models, the result varies significantly if they are considered standard or high consumption profiles, when European guidelines clearly bet on reductions in energy consumption.

The best amortizations are obtained with the renovation of carpentry, around 23 years, similar to the interventions in roofs for the case of the block building (Figures 11 and 12).

Results of the "cost30" indicator offer different values, depending on the model. In the block building costs should be reduced by 61% for total intervention, and around 45% for exterior and interior facade interventions. In the case of the building between town houses, results are less demanding, due to the lower surface area of the outer envelope with reductions of 23% being required for total intervention, 35% on roofs and approximately 5% on exterior and interior facade interventions.

CONCLUSIONS

The methodology developed in this work is based on the European framework and allows generating valid indicators, however, the definition of a methodology for Spain would clarify some criteria of calculation and energy prices that affect the obtained results.

A moderate increase of 4% in the price of energy has been considered, but its variability in a 30-year horizon would significantly modify the results obtained; however, its increase would improve amortization terms.

There is no single optimal cost value as various options are presented, depending on the case. In most of them, total intervention provides the best values; although it represents the highest initial investment cost, this is offset by the reduction in energy consumption and costs during its 30-year useful life. They also show adequate optimal costs for interventions on facades and windows.

Considering the climatic zones, the best optimal costs are obtained for zones A3 and A4, representative of milder climates and with lower consumption expenses. Regarding models, these costs are for the building between town houses, which is representative of buildings of low construction quality and that offer a wide margin of improvement in the reduction of energy consumption.

In addition to the optimal cost, it is necessary to include the family income parameter in energy accounting and assess interventions based on salary income. In that sense, the variant of total intervention is the one that involves more economic effort, being the most appropriate - due to its lower initial cost - improvement in facades and windows. There are different levels of investment, ranging from € 440/family to € 17,960/family, among which there is a range of proposals that represent from 1 to 26 times the minimum interprofessional salary.

In relation to amortization, not all interventions are viable and depend on the type of building and the climatic zone. Therefore, the study proposes the "cost30" indicator as an adequate value to set costs for amortizations in 30 years. In the case of the building between town houses, it is not necessary to significantly reduce the investment cost, on the contrary, in the block building some of the solutions should reduce more than 60% of their costs. This measure could be encouraged with state aid and subsidy plans, or through cheaper products.

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ENVIRONMENTAL IMPACT ASSESMENT BY MEANS OF INDICATORS EMBEDDED IN A BIM MODEL OF SOCIAL HOUSING

EVALUACIÓN DE IMPACTO AMBIENTAL MEDIANTE LA INTRODUCCIÓN DE INDICADORES A UN MODELO BIM DE VIVIENDA SOCIAL

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RESUMEN

Building Information Modeling (BIM) constituye una herramienta versátil para analizar el ciclo de vida de los edificios y el uso eficiente de los recursos, reducción, reuso y reciclado de residuos de construcción y demolición hacia un parque edilicio sin carbono para 2020 en Europa. Este trabajo propone una nueva metodología para incorporar indicadores: energía incorporada, emisiones de CO2, residuos de construcción y demolición además de sólidos urbanos, en modelos BIM que evalúan el impacto ambiental siguiendo la estructura de la Base de Costes de la Construcción de Andalucía (BCCA). Se eligió un bloque de vivienda social en Sevilla, como caso de estudio, para focalizarse en el análisis de su estructura de hormigón armado debido a su alto impacto.Los resultados agrupados por tarea e indicador muestran el rol preponderante del hormigón. Por el contrario, el acero demuestra ser menos energo-consumidor, generando menos emisiones y permitiendo reducir los residuos mediante reciclaje. Según la discriminación por tareas, se destaca el bajo impacto de las fundaciones frente a la superestructura resistente. Asimismo, cada metro cuadrado de construcción típica genera 76.11 de residuo de construcción y demolición, siendo 76,11 kg mixto proveniente del hormigón y 0,34 kg, del acero.

Palabras clave
Energía incorporada, emisiones de CO2, residuos de demolición y construcción, diseño por ordenador

ABSTRACT

Building Information Modeling (BIM) has become a versatile tool to analyze the building life cycle and to achieve the efficient use of natural resources and the reduction, reuse and recycling of construction and demolition waste towards the goal of a decarbonized building stock for 2020 in Europe. This research proposes a new methodology to introduce embodied energy (EE), carbon emissions (CE), construction and demolition waste (CDW), and urban solid waste (USW) indicators into BIM models that assess environmental impact following the structure of the Andalusian Construction Cost Database (ACCD). A block of social housing was chosen as a case study in order to focus on the analysis of its reinforced concrete structure due to its high impact. The results, grouped by task and indicator, show the dominant role that concrete plays in environmental impact. In contrast, steel proved to consume less energy and generate fewer CE as well. Moreover, steel may be recycled, while reducing the quantity of waste. When analyzed by task, the foundations cause much less impact than the tough superstructure. Likewise, each square meter of the typical housing block generates 76.11kg of CDW, with 76.77 kg of mixed concrete waste and 0.34 kg of steel waste.

Keywords
embodied energy, CO2 emissions, construction and demolition waste, computer-aided design

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INTRODUCTION

The Architecture, Engineering & Construction (AEC) sector plays a key role in the environmental impact that human activity provokes. Buildings are responsible for 40% of the energy consumption, 36% of the CO2 emissions and 40% of the CDW in the European Union (EU) ("Buildings - Energy - European Commission" 2017) . EU Directives on energy consumption reduction (Official Journal of the European Union 2010) and energy efficiency in buildings (Official Journal of the European Union 2012) determine that by 2020, every new building shall be nearly Zero Energy (nZEB). Among the EU Horizon 2020 program main objectives, the achievement of a more efficient society and economy in relation to the use of natural resources and raw materials and a sustainable energy use appears as a main goal to fight against Climate Change ("United Nations Framework Convention on Climate Change" 2018).

The AEC sector consumes more than 20% of the fuel (Tiwari 2001), and 40% of the material resources (López-Mesa et al. 2009) worldwide. This sector faces the challenge to reduce energy consumption and CE but the increasing building stock makes them difficult to reach in the medium term (Sandberg & Brattebø, 2012).

Years before, operating energy (OE) represented the main factor in building energy consumption whilst embodied energy (EE) accounted for 10-20% of the energy in the building life cycle. However, as energy efficiency makes OE consumption decrease, EE becomes more important for environmental impact assessment. González and Navarro consider that CO2 emissions can be reduced to 30% of its original value by selecting low impact materials (González and García Navarro 2006). Rodríguez Serrano et al. Rodríguez Serrano and Porras Álvarez, 2016) conclude that the major emissions impact of urbanization and buildings take place during construction and therefore, later savings due to OE reductions are very modest in comparison. As Abanda et al. contend (Abanda, Oti, and Tah 2017), it is crucial to design automated systems to compute EE and CO2 emissions in buildings in accordance with well-established standard measurement and pricing databases.

Whereas the building industry generates 35% of the total industrial waste worldwide, the EU manufacturing industry consumes 40% of the natural resources (Mercader Moyano, M. 2010), but only 25% of the generated CDW is recovered (IEA 2013). The Royal Spanish Decree 105/2008 (Spanish Government – Ministry of the Presidency, 2008) has already regulated CDW production and management, taking into account the European Waste Catalogue (Official Journal of the European Communities and Commission Decision 2001/118/EC of wastes 2001) . The II CDW Spanish Plan for 2008/2015 showed that less than 18% of the building & infrastructure activity CDW is recycled (Ministry of Environment and Rural and Marine Affairs 2008). Moreover, Solís considers that only 15% of the CDW is recycled in Spain, far from other European members achievements (Solís Guzmán, J., 2010).

Methods to articulate the whole building process data are still developing, whilst the consideration of environmental issues during the design stage remains as one of the biggest challenges for designers. Furthermore, the European Committee for Standardization recommends to integer the building production from an environmental perspective to comply with European Directives on Sustainability on Construction Works (CEN European Committe for Standardization 2012). The European Union Directive 2014/24/EU on Public Procurement states that "for public works contracts and design contests, Member States may require the use of specific electronic tools, such as building information electronic modeling tools or similar". Spain ("Spain Launches BIM Strategy with Penciled-in 2018 Mandate | BIM+" 2018), UK (AEC (UK)), Germany (ZukunftBAU 2013) and France (B. Delcambre) have already begun to transpose these Directives into their local governments regulations. But important barriers still remain when referring to the AEC industry: environmental data accessibility, too high expert knowledge, and difficult identification of appropriate alternative components or materials (Bey, Hauschild, and McAloone 2013).

Building Information Modeling (BIM) is increasingly used in the AEC sector to deliver integrated preplanning, design and project management mainly for new buildings (Mousa, Luo, and McCabe 2016). A BIM-based tools review for environmental impact assessment showed that most of them need to couple BIM software with other applications to obtain environmental indicators quantification. A review on BIM-sustainability integration conducted during the whole building life cycle remarked that environmental, social, and economic sustainability considers design stage as the core of the matter (Chong, Lee, and Wang 2017). Other authors reviewed research on BIM/LCA integration analysis and its possibilities of being simplified in terms of input-output data and LCA results (Soust-Verdaguer, Llatas, & García-Martínez, 2017) and remarked that the best solution would be to remain inside BIM environment to facilitate the interaction between design and environmental performance (Antón and Díaz 2014). Most of the reviewed tools consist of applications to connect BIM model with environmental data like Tally ("Tally" 2018) and Revit (Najjar et al. 2017). Marzouk et al. proposed a combination of several software tools: Autodesk Revit ("Revit Family | BIM Software | Autodesk," n.d.), Revit DB link ("About Autodesk Revit DB Link | Revit Products | Autodesk

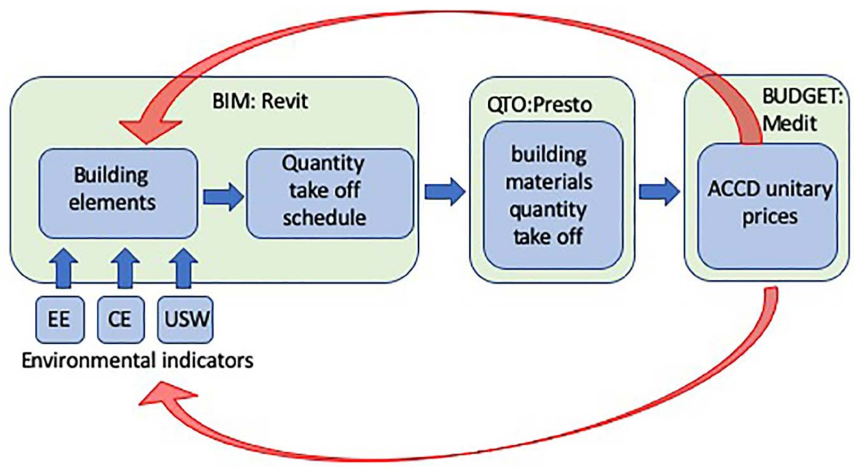

Figure 1. Environmental indicators embedded into BIM families and types Source: the authors

Knowledge Network," n.d.), Microsoft Access ("Database Software and Applications | Microsoft Access," n.d.) and ATHENA Impact Estimator ("IE for Buildings | Athena Sustainable Materials Institute," n.d.) when measuring direct and indirect carbon emissions (CE) in construction projects (Marzouk, Abdelkader, and Al-Gahtani 2017). Chen and Pan (Chen and Pan 2015) presented a multi-criteria decision making in low carbon building measures, combining Revit, eQuest ("EQUEST" 2018) and Promethee (Gul et al. 2018). Ajayi et al (Ajayi et al. 2015) explore a combination of Revit Architecture, the add-in Green Building Studio (GBS) and ATHENA for global warming potential (GWP) and health impact assessment. Azhar et al (Azhar et al. 2011) coupled Revit with IES Virtual Environment ("Introducing IESVE Software | Integrated Environmental Solutions" 2018) to compute carbon emissions and embodied energy to convert them into LEED credits ("LEED | USGBC" 2018). Basbagill et al (Basbagill et al. 2013) developed a BIM model utilizing DProfiler (Chelsea 2018) linked with eQuest ("eQUEST," n.d.) inside a BIM environment while results are manually charged into SimaPro and Athena EcoCalculator to obtain CE. Ilhan et al (Ilhan and Yaman 2016) developed a green building assessment tool, utilizing Graphisoft ArchiCAD® linked to BREEAM materials database. Inyim et al (Inyim, Rivera, and Zhu 2015) introduced Simulation of Environmental Impact of Construction (SimulEICon), which is a BIM extension designed to aid in the design stage decision-making process of a construction project.

Gan et al . (Gan et al. 2018) developed a holistic approach to evaluate embodied and operational carbon in high-rise buildings, utilizing Revit and a parametric plug-in, Dynamo. In later research, the same team assessed CE reduction when replacing steel and cement for recycled materials (Gan et al. 2017). Yang et al . (Yang et al. 2018) deployed a one-way workflow to calculate operation and materials energy and CO2eq.

As Wong et al . pointed out, BIM tools should include the three Rs concept (reduce, reuse and recycle) in environmental impact analysis for both new and retrofitting projects (Wong and Zhou 2015) to achieve sustainability goals. Moreover, CDW and USW should be taken into account in a broad sustainability overview because they affect EE/CE balance during the construction process. Cheng and Ma (Cheng and Ma 2013) developed an add-on application manager for CDW. Yehesis et al . (Yeheyis et al. 2013) proposed a conceptual CDW management framework to maximize the 3Rs and minimize the disposal of construction waste by BIM building projects LCA. Sáez et al . (Villoria Sáez et al. 2018) pointed out that the major CDW quantity corresponds to vertical envelope in building retrofit.

The integration of BIM models with standard measurement methods to obtain EE and CE quantification was also reviewed. Abanda et al . (Abanda, Oti, and Tah 2017) developed a specific application to link BIM models with the New Rules of Measurement (NMR), the UK standard for public procurement (Surveyors 2018), utilizing Bath Inventory of Carbon and Energy (Bath ICE) (Jones, C. and Allen, Stephen 2017).

Lützkendorf et al . expressed that interoperability with other software to achieve material quantity, and cost estimation will hasten the design process, allow alternate solutions comparison and produce better outcomes (Lützkendorf et al. 2015).

However, BIM software still needs to meet building designers requirements (Lamé, Leroy, and Yannou 2017). One of the main barriers that designers face when delivering eco-efficient building projects is the specific

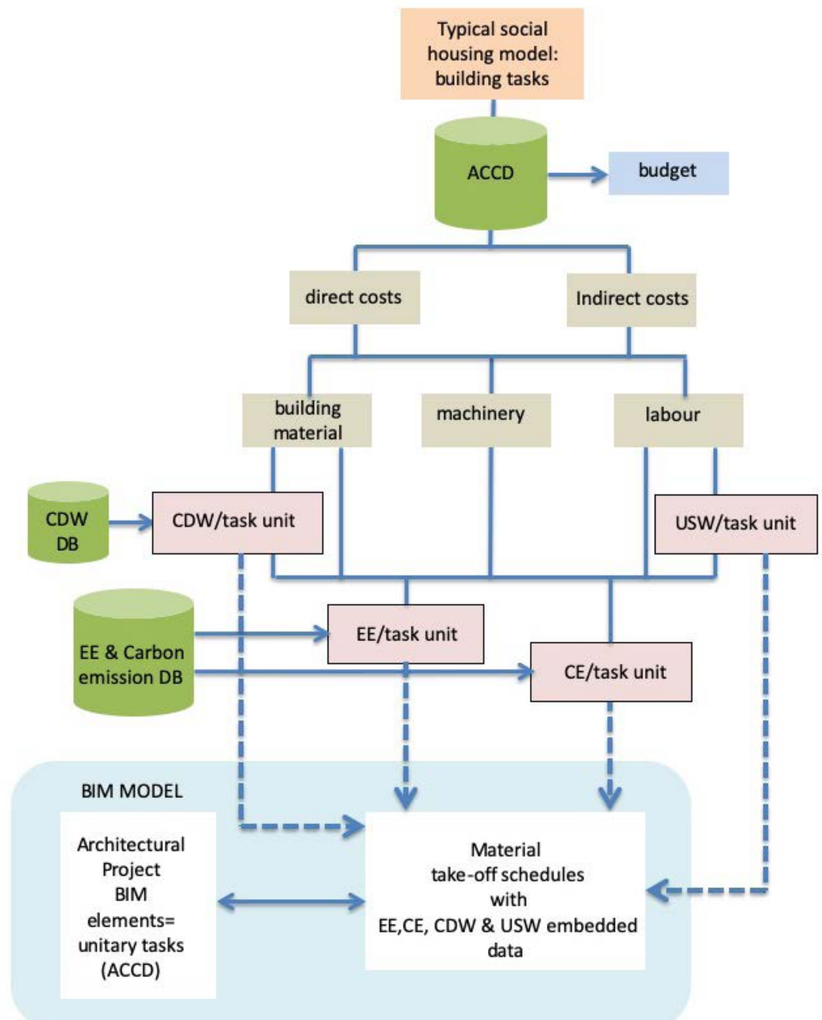

Figure 2: Synthesized methodological workflow Source: the authors

expertise to deal with different software, databases and methodologies. Despite this, there is an increasing trend to integrate assessments systems, databases, consultants and providers (Fiès, Lützkendorf, and Balouktsi 2013). While some designers are considering complex data and assessment tools application; others feel that they are still overburdened.

The aim of this study is to fill the gap of environmental impact assessment in concept design, through BIM embedded indicators. This strategy facilitates the designer choice of the best alternatives to reduce environmental impact in an open framework. The work proposes a bottom-up approach for CDW, USW, EE and CE quantification according to the work breakdown structure (WBS) of ACCD (Fig.1). Presto® and Medit® use the BIM buildings elements to extract the bill of quantities and costs ("Acae Presto" 2018) ("Medit Mediciones en BIM con REVIT" 2013).

MATERIALS AND METHODS

The methodology is appropriate for the concept design even though material definition is not completely defined because ACCD provides a complete catalogue of construction systems and materials which are available as Revit elements. The workflow is divided into three steps to quantify CDW, USW, EE and CE of a new or a retrofitted building (Fig. 2):

Decomposition of each construction cost database chapter into its lower levels: building materials, work labor, and machinery, including auxiliary tasks and indirect costs . Addition of environmental parameters: CDW, EE, CE and USW to the WBS of ACCD to obtain the indicators
.
Embedding of environmental indicators into the BIM material take-off schedules to quantify EE, CE, CDW and USW .

DECOMPOSITION OF BUILDING TASKS

Spanish current regulations commit to deliver new building projects in BIM file format, utilizing CCDs for public tendering. Andalusia counts on ACCD which is a free downloadable online database. It provides a detailed description and measurement of all the tasks carried out along the building process while files can be coupled with QTO and cost calculation software formats (FIE-BDC Association).

The ACCD divides the building tasks into chapters that quantify building material, work labor and machinery called DIRECT COSTS (DC) while adding a percentage for general tasks called INDIRECT COSTS (IC) (Barón, J. et al. 2017) which affect the whole building process as general lighting, electricity and fuel for machinery and technical and auxiliary staff work. Auxiliary tasks break down from main tasks.

CDW is developed in specific chapters: one for each kind of waste (mixed, wood, paper and cardboard, steel, inert soil among others). Each chapter comprehends the items that compose a task measured in specific units. For CDW quantification, we applied the methodology developed by Ramírez de Arellano (Ramírez de Arellano Agudo 2002), included in the ACCD in 2017, and based on the National Decree to regulate the production and management of CDW (Spanish Government – Ministry of the Presidency, 2008), and on the European Waste List 2000 (Official Journal of the European Communities and Commission Decision 2001/118/EC of wastes 2001) . The methodology is fully described in (Mercader-Moyano and Ramírez-de-Arellano-Agudo 2013) and (Marrero and Ramirez-De-Arellano, 2010).

ADDITION OF THE ENVIRONMENTAL PARAMETERS: EE, CE, USW AND CDW TO THE ACCD WBS

The procedure utilizes the ACCD budget as a framework to embed the environmental indicators (Freire Guerrero, A. and Marrero Meléndez, M. 2015). Data are divided into two main branches: Direct Costs (building materials, machinery, labor) and Indirect Costs (general electricity, water and waste).

EE and CE values were extracted from Ecoinvent database (Swiss Centre for Life Cycle and Inventories 2017), BEDEC (Instituto de Tecnología de la Construcción de Cataluña 2017). Staff food EE and USW values were extracted from (Solís Guzmán, J., 2010) and (Freire Guerrero, Antonio 2017) research. Electricity CO2 emissions were obtained from the Andalusian energy matrix whose electricity mix produced 419,9 tCO2/GWh, equivalent to 0.117 kgCO2/MJ, in 2016 (Agencia Andaluza de la Energía 2017).

Environmental parameters addition to direct costs

Direct costs (DC) equations of each unitary price are shown below. Eq. 1 shows the EE of each item integrating a unitary price.

(1) $$EE_{DC} = \sum_{i\epsilon I} EE_i$$

I={building material; machinery, staff food, USW, CDW per type}
EE= basic task EE in MJ

As building materials can be measured in m3, kg, ton, or m2 among others, EE must be converted to the corresponding target unit (MJ/TU) (Table 1).

Building material	unidad	EE MJ/TU	CE kgCO2/ TU
Steel	kg	40.00	2.80
HA-25/B/20/IIa Concrete	m3	6209.97	159.46
Pinewood	m3	3.00	714.00
Ceramic hollow brick	millas	5290	487.60
Sand	m3	247.51	48.00

Table 1. EE and CE according to ACCD unitary price units Source: the authors

Machinery is computed in hours, depending on the EE/h of each machine type (Eq. 2).

(2) $$EE_m = \sum_{m\in M} Q_{\ m} x EE_m/h$$

M = {tilting truck, front loader, backhoe, vibrator, forklift}

USW quantification is calculated with a fixed value per labor hour (0.077 kg/h)
Work labor is computed in hours to calculate $EE_{worker\ food}$ EE

(3) $$EE_{staff\ food} = \sum_{i=1}^{n} Q_{\ i} x EE_{worker\ food}/h$$

(4) $$EE_{USW} = \sum_{i=1}^{n} Q_{\ i} x EE_{USW}/h$$

$_{USW}$ (Eq. 3-4)
Q_i=length of a basic task execution in h for worker i
n= workers
$EE_{worker\ food}$/h=EE per labor hour
EE_{USW}/h= USW per labor hour

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CDW is computed in different units according to waste disposal (Eq. 5).

(5) $$W_{o\in O} = C_{Ro} x C_{Co} x C_{To}$$

W_o is the resulting coefficient, one per each kind of waste O={cardboard/paper, wood, inert soil, aluminum, copper, bronze, iron, steel, arid aggregate/stone, plastic/synthetic, glass and mixed waste}

The effective waste quantity is shown in Eq. 6.

(6) $$EE_{CDW} = \sum_{b\in B} Q_b \; x \; W_o \; x \; RF_o x \; EE_o$$

Q_b is the building material quantity
B={building materials}
RF_o= recycle factor which reduces EE
EE_o = unitary EE for waste type

The DC carbon emission (CEDC) is shown in Eq. 7.

(7) $$CE_{DC} = \sum_{i\in I} CE_i$$

I={building material; machinery, staff food, USW, CDW per type}
CE_i is the basic task CE in $kgCO_2$

CE/food kg is fixed as 0.24 kgCO2/food kg (Eq. 8 and Eq. 9).

(8) $$CE_{staff\ food} = \sum_{i=1}^{n} Q\ _i x CE_{worker\ food}/h$$

(9) $$CE_{USW} = \sum_{i=1}^{n} Q\ _i x CE_{USW}/h$$

Q_i= basic task execution in h for worker i
n= workers
CEworker food/h= generated CE per labor hour
CEUSW/h= generated CE USW per labor hour
In the case of the CDW, we add a recycle factor RF, which depends on the waste type and reduces CE (Eq. 10):

(10) $$CE_{CDW} = \sum_{b\in B} Q_b \; x \; W_o \; x \; RF_o x \; CE_o$$

RF_o= recycle factor
CEo = unitary carbon emissions per waste type

Environmental parameter addition to indirect costs

Indirect Costs (IC) are a fixed percentage of Direct Costs: 10.62% of DC is adopted for the typical social housing in Andalusia.

Energy consumption is divided into three categories: general staff, electricity and fuel, according to typical social housing IC analysis (Eq. 11).

(11) $$EE_{IC} = \sum_{s\in S} EE_{ICs} \; x \; IC_s + \sum EE_{ICSUW}/TU$$

EE_{ICs}= IC EE in MJ
IC_S= corresponding percentageS={staff, electricity, fuel}
$EE_{IC\ USW}$=IC EE of staff food consumption USW in MJ
The EE of the CDWIC is calculated in the same way as an IC unitary task.

ACCD UNITARY PRICE+ENVIRONMENTAL INDICATORS

The new WBS of an ACCD UNITARY PRICE+ ENVIRONMENTAL INDICATORS (EUP) comprehends EE, CE, USW and CDW addition (Fig. 3)
Source: the authors

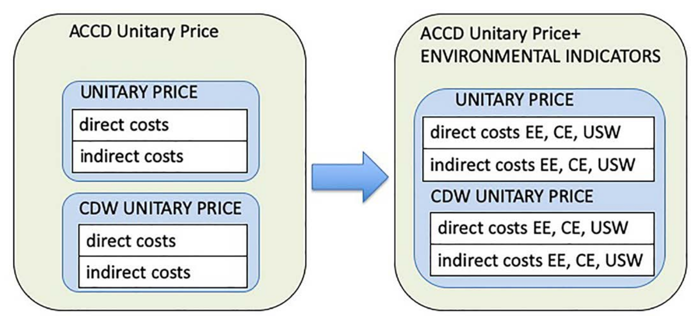

Fig. 3. WBS of ACCD unitary prices and environmental unitary prices (EUP), showing the addition of the environmental indicators and the merging of the main unitary price with the corresponding CDW unitary prices

The ratio between EE, CE, CDW and USW and EUP unit calculates the EE, CE, CDW and USW indicators (Eq. 12-15).

(12) $$EE_{EUP}\ indicator\ (MJ/EUPunit) = \frac{EE_{\ EUP} + EE_{CDW\ EUP}}{EUPu}$$

(13) $$CE_{EUP}\ indicator\ (kgCO_2/EUPunit) = \frac{CE_{\ EUP} + CE_{\ CDW\ EUP}}{EUPu}$$

(14) $$CDW_{EUP}\ indicator\ (CDWunit/EUPunit = \frac{CDW_{CDWEUT}}{EUPu}$$

(15) $$USW_{EUP}\ indicator = \frac{USW_{\ EUP} + USW_{CDW\ EUP}}{EUPu}$$

EUP= environmental unitary price unit
CDW EUPu= CDW environmental unitary price unit

ENVIRONMENTAL COEFFICIENTS EMBEDDING INTO BIM MODEL AND QUANTIFICATION

Then, the environmental indicators are embedded as new parameters in each BIM family. BIM elements are measured in the same units as EUPs. Autodesk Revit generates the material take-off schedules for each element type, so we are able to add environmental parameters: EE, CE, CDW and USW values per unit. Finally, the program calculates the total quantities for each parameter.

CASE STUDY

A SOCIAL HOUSING BLOCK: THE REINFORCED CONCRETE STRUCTURE

This research develops the environmental indicators quantification applied to the reinforced concrete structure of a typical social housing block in Seville (Fig. 4) at the conceptual design. This typology represents one of the most spread in Andalusia and it has been extensively described (Mercader Moyano, M. 2010; González-Vallejo, Marrero, and Solís-Guzmán 2015). This kind of buildings usually has 2/4-storey high reinforced concrete structure, aluminum carpentry, and flat slab roof (Marrero Meléndez, M. et al. 2015). The reinforced concrete structure accounts for a large environmental impact (De Wolf, Pomponi, and Moncaster 2017).

Fig. 4: Social housing block in Seville Source: the authors

ENVIRONMENTAL INDICATORS

As an example, Table 2 shows the environmental indicators addition to each unitary price for the cleaning concrete layer.

BIM MODEL

The floor plan is a 23m side square and the building has two floors, which account for 1,058 m2. We link an ACCD unitary task to each building element. Therefore, certain building elements, which do not have any equivalent BIM element like formworks or excavations, are drawn as new elements: surfaces to measure formwork areas for structural elements (pillars, stairs, slabs and beams) and boxes for excavations (Fig. 5).

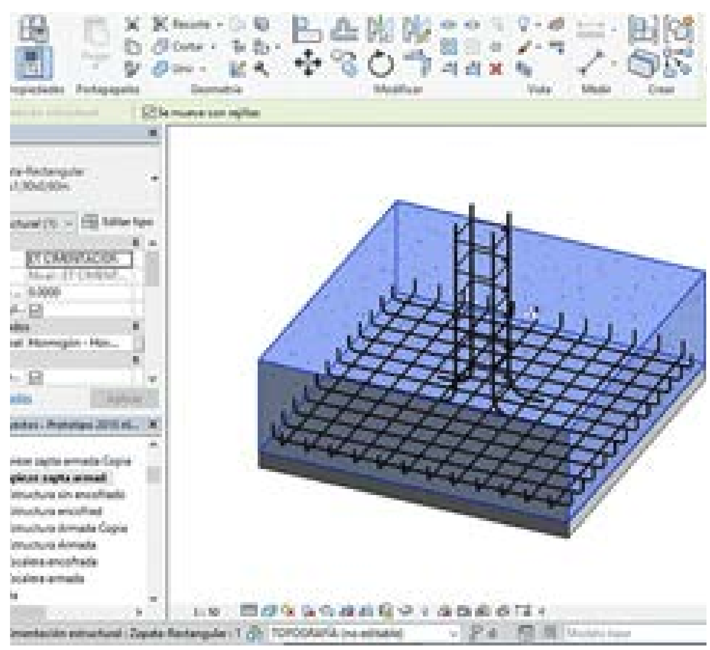

Fig. 5. Revit screenshot showing the BIM elements in correspondence with the Foundation Slab and Pile cap ACCD unitary price Source: the authors

ENVIRONMENTAL INDICATORS EMBEDDING

Table 3 synthesizes the environmental coefficients per unitary task of the building structure, embedded into the BIM model as new parameters.

1 https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Revit-DocumentPresent/files/GUID-F8270A42-CA71-46C7-B145-85EC2CB8E4A1-htm.html

Evaluación de impacto ambiental mediante la introducción de indicadores a un modelo bim de vivienda social
María del Pilar Mercader Moyano, Patricia Edith Camporeale, Elías Cózar-Cózar
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COD.	UN	DESCRIP.	Q/u TU	unitary price €/TU	WO/ TU	tipo	CDW Q	unit	EE MJ	CE kgCO2
03WSS80000	m2	CLEANING CONCRETE LAYER med. width: 10 cm	1	8.62						
CH04020	m3	Pre-elaborated HM-20/P/20/I concrete	0.11						261.80	51.20
TP00100	h	Specialised worker	0.08						4.07	2.44E-01
	kg	USW			0.077	USW	6.16E-03	kg	5.05E-02	1.50E-03
TO02200	h	2nd cat. Worker	0.05						2,55	0,152
		USW			0.077	USW	3.85E-03	kg	3.16E-02	9.35E-04
Cost. Ind.	10.62% DC			0.92						
	h	staff	0.01						0.50	0.03
	kg	USW			0.077	USW	7.70E-04	kg	6.30E-03	1.87E-04
		electricity	12.85% IC						0.44	0.59
		fuel	72.76% IC						2.52	0.17
17RRR00420	m3	MIXED WASTE REMOVAL max. dist. 15 km		12.5						
	m3	Concrete waste	0.01	0.21	0.11	mezcla desecho	0.01	m3	-17.85	-0,20
ME00300	h	Front loader	2.00E-04	0.48					0.15	0.01
MK00100	h	Tilting truck	3.00E-03	7.68					1.26	0.07
Cost.Ind.	10.62% CDW DC			0.02						
	h	staff	3.20E-03		-				0.01	
	kg	USW			0.077	USW	2.46E-04	kg	2.00E-03	5.97E-05
		electricity		12.85% IC					0.01	0.01
		fuel		72.76% IC					0.05	3.46E-03
ENVIRONMENTAL INDICATORS						USW kg/m2		1.80E-02		
						MIXED WASTE m3/m2		1.00E-02		
						EE MJ/m2		255.60		
						CE kgCO2/m2		52.28		

Table 2. Cleaning concrete layer. Med. width: 10 cm. Source: modified from ACCD by the authors

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TASK GROUP	UNITARY TASK	unit	CDW coefficients						EE	CE
			USW kg/u	wood ton/u	inert soil ton/u	paper & cardboard kg/u	steel ton/u	mixed m3/u	MJ/u	kgCO2/u
DEMOLITION & PREVIOUS WORKS	MECHANICAL LAND CLEARING	m2	4.64E-04	8.00E-02					19.92	1.26
LAND CODITIONING	BOX EXCAVATION, MEDIUM CONSISTENCY SOIL	m3	3.36E-03		1.25				211.60	13.03
	FOUNDATION SLAB MECHANICAL EXCAVATION, MED. CONSIT., max. depth: 4m	m3	1.31E-02		1.25				267.97	17.57
	TRENCH MECHANICAL EXCAVATION, max. depth: 1.5m,width: 40 cm	m3	1.34E-02		1.25				267,26	17.42
FOUNDATIONS	FOUNDATION CORRUGATED STEEL RODS B500S	kg	1.70E-03				9.79E-06		47.10	3.38
	LOST BRICK FORMWORK OF RING BEAMS, FOUNDATION SLABS & PILE CAPS	m2	1.88E-02	2.60E-03		20.60	2.60E-03	9.10E-03	708.15	36.83
	FOUNDATION & RING BEAM CONCRETE HA-25/B/20/IIa	m3	4.26E-02					9.10E-03	2326.53	531.32
	FOUNDATION SLAB & PILE CAP CONCRETE HA-25/B/20/IIa	m3	4.00E-02					0.11	2516.52	304.78
	CLEANING CONCRETE LAYER med. width: 10 cm	m3	1,80E-02					0,01	255,60	52.28
STRUCTURE	CORRUGATED STEEL RODS B500S	kg	4.26E-02				1.08E-05		47.10	3.38
	WOOD FORMWORK REMOVAL FROM CONCRETE ELEMENTS	m2	1.54E-02						10.69	0.92

STRUCTURE	METAL PANEL FORMWORK REMOVAL FROM CONCRETE ELEMENTS	m2	8.47E-03						5.92	0.50
	PINEWOOD FORMWORK FOR CONCRETE SLABS	m2	6.39E-02	1.00E-06			1,75E-04		80.55	10.57
	METAL FORMWORK FOR PILLARS	m2	2.54E-02				2,00E-05		46.97	2.94
	REINFORCED CONCRETE HA-25/P/20/Iia FOR SLABS	m3	6.80E-02					0,11	2344.39	486.19
	REINFORCED CONCRETE HA-25/P/20/Iia FOR PILLARS	m3	5.10E-02					0,11	2044.20	328.82
	WOOD FORMWORK REMOVAL	m2	1.55E-02						2.71	0.27
	HOLLOW BRICK WALL width:5 cm	m2	4.39E-02	3.40E-02		0.27	3.50E-06	4.00E-03	1014.83	85.13

Table 3: Environmental indicators: EE, CE, USW and CDW per type according to the EUPs of the reinforced concrete structure Source: the authors

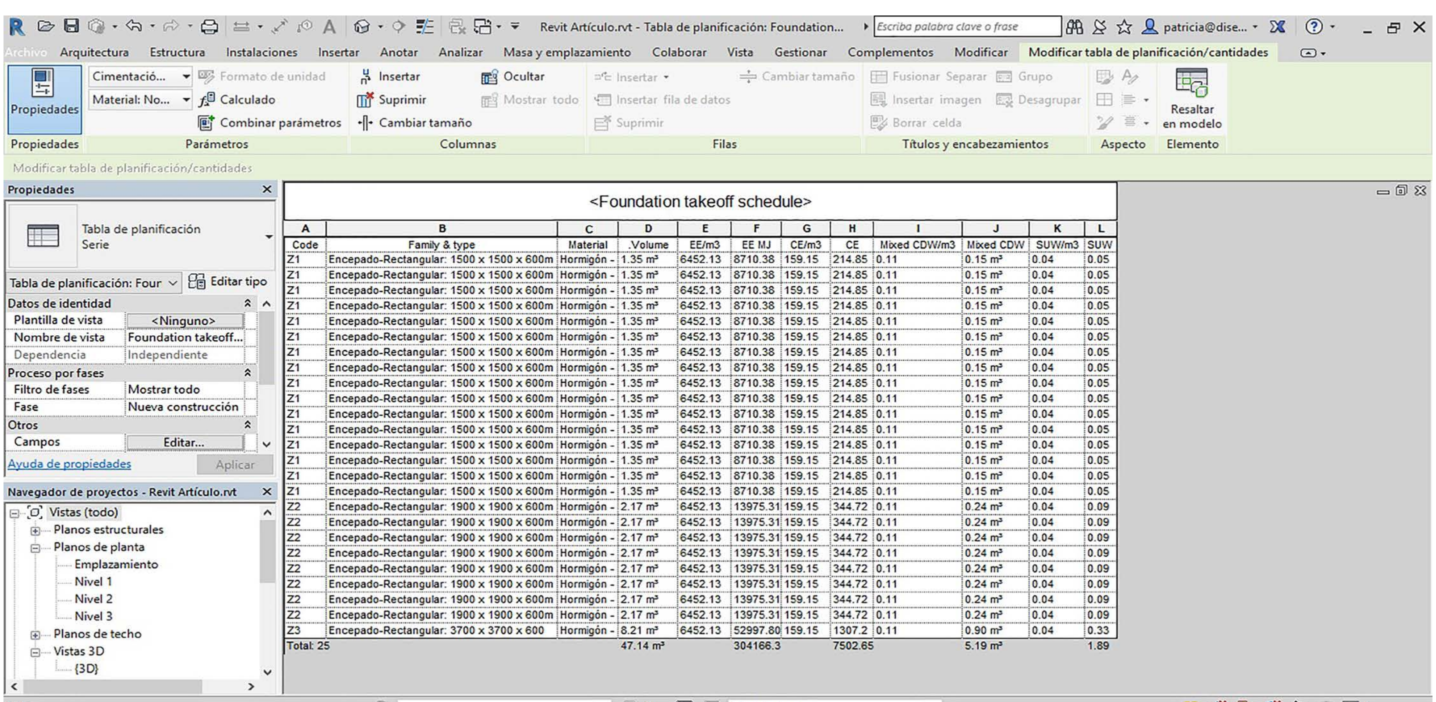

Fig. 6: Revit screenshot showing material takeoff schedule of slab foundation family with environmental embedded data Source: the authors

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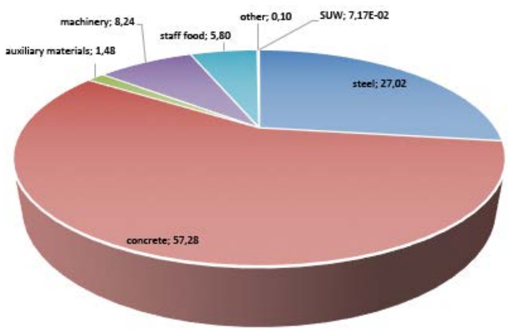


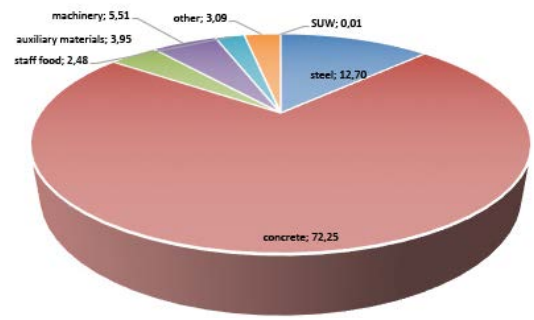
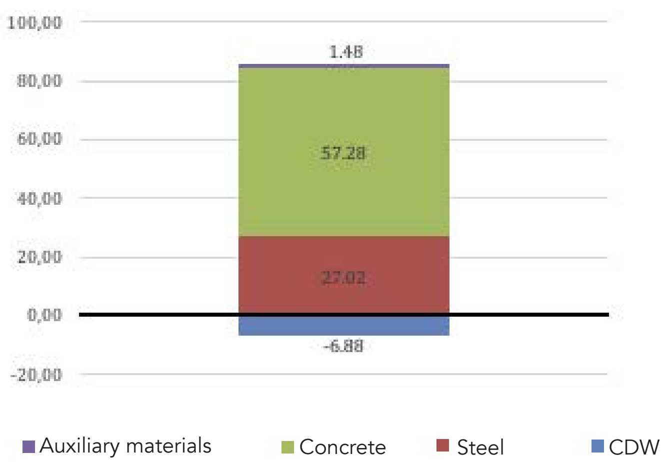


Fig. 7. Reinforced concrete structure EE percentages Source: the authors
Fig. 8. Reinforced concrete structure CE percentages Source: the authors



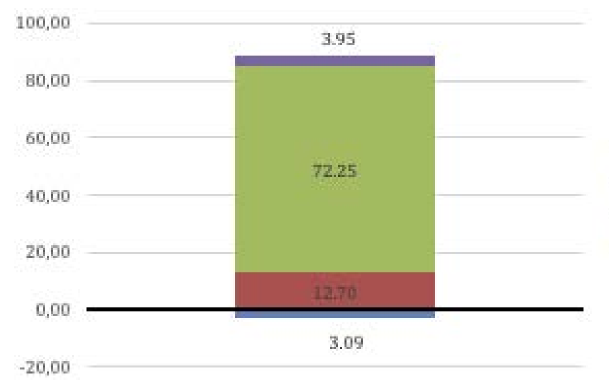
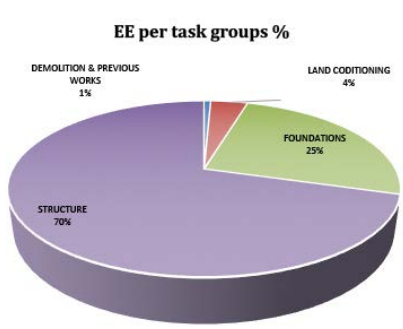


Fig. 9. Construction materials EE & CDW percentages Source: the authors
Fig. 10. Construction materials CE & CDW percentages Source: the authors



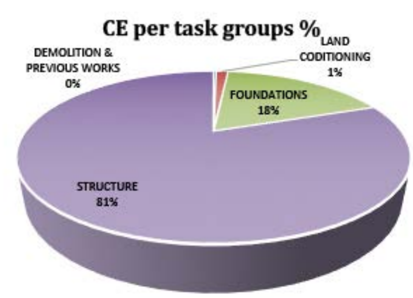


Fig. 11. EE percentages corresponding to the reinforced concrete load bearing structure, divided by task group Source: the authors
Fig. 12: Reinforced concrete structure CE percentages divided by task group

After drawing the whole model, Revit extracts the Material Takeoff Schedules, listing the sub-components or materials of any Revit family. The charts quantify USW, CDW, EE and CE, for each Revit family in real time, reflecting any change made in the model. Fig. 6 shows the foundations slabs and pile caps take-off schedule.

RESULTS AND DISCUSSION

Construction materials, USW, CDW, EE and CE are quantified inside Revit. The results are analyzed after extracting the material takeoff schedules of every BIM element, according to the EUPs (Fig. 7-8).

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In Fig 9 and 10, EE-CE reduction due to CDW recycling was calculated considering that only 15% of the waste is recycled in Spain (Solís Guzmán, J. 2010). As it is expected, the CDW EE-CE reduction is not considerable: -6.88 % and 3.09% respectively.

When analyzing the task groups, EE and CE show nearly similar results (70%) (Fig. 11-12). These task groups comprehend not only land conditioning, excavations and construction, but CDW tasks as well. The division into task groups, which is taken from the ACCD, allows the designer to evaluate different types of construction systems for each group by modifying the BIM model and changing the subsequent coefficients in the material takeoff schedules. We can infer that the superstructure plays a key role to achieve substantial EE and CE decrement (Ferreiro-Cabello et al. 2016).

The next step is to quantify the load bearing structure CDW-USW for a typical social housing (TSH) block per square meter (Fig. 13). If inert soil and wood are left apart since EE and CE are nearly null and can be recyclable at low cost, the load bearing structure generates 75.77 kg of mixed CDW, 0.34 kg of steel CDW, 0.69 kg of paper & cardboard CDW and 0.13 kg of USW per square meter. Source: the authors

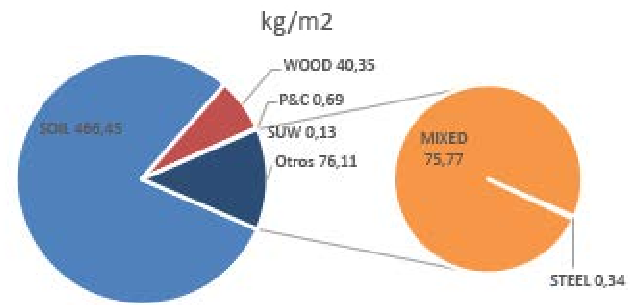

Fig. 13. TSH reinforced concrete structure CDW kg/m2- USW kg/m2
Source: the authors

CONCLUSIONS AND FUTURE WORK

The framework developed in this study allows embedding environmental indicators into BIM models for EE, CE, USW and CDW quantification, following the ACCD WBS. If applied at the conceptual design, as BIM regenerates geometry in real time, the designer is able to evaluate different formal and technical solutions when decisions impact most on the LCA. In advanced stages of design, making substantial modifications to the building project demands more time and money than in the first stages.

The main findings of this research are:

indicators development that constitutes a quantitative assessment corner stone.
the methodology that considers designer needs from a holistic perspective that fosters environmental criteria inclusion from early design stages by simplifying indicators introduction process .
the calculation of the environmental performance together with architectural design, by reflecting any change in a seamless workflow that feeds the process back in real time .

In this case study about a housing block reinforced concrete structure, these results verify other authors assumptions: it is better to use low EE materials than high EE ones because of the poor recycling rate (González and García Navarro, 2006). Furthermore, the TSH load bearing structure generates 76.11 kg/m2 of CDW: 75.77 kg/m2 of mixed CDW, mainly due to concrete and only 0.34 kg/m2 of steel CDW. When considered by task, foundations present a much less impact than the superstructure.

These outputs offer a gap to reduce environmental impact by innovating load-bearing structure solutions. Low EE/CE materials like wood or recycled inert aggregates can offer good alternatives. Andalusian traditional construction system should be reformulated in order to reduce natural resources depletion, energy consumption, and CE and USW/CDW generation.

One of the limitations of these indicators is that they are adapted to the WBS of the ACCD since they were created to enhance Andalusian Revit models to obtain the bill of quantities and costs through other programs like Presto and Medit.

In future work, it is expected to extend the environmental indicators to every unitary task to get a complete environmental assessment of the building construction that allows the comparison between different construction systems and materials within BIM environment. When added to the ACCD, they will be available to users without deep expertise in environmental impact assessment tools, making this a less error-prone and time-consuming task.

A future line of research may include the application of the methodology to a set of representative projects to extend the results to a national level and the addition of the environmental outputs to certification systems like BREAM and LEED. Other line of research could be to achieve indicators access from other platforms like Navisworks since now they are only available in the Revit material take-off schedules.

This approach to the building production process constitutes a major contribution to the built environment sustainability and the cities resilience to mitigate Climate Change since designers keep control on each component and system in real time at the conceptual design stage.

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TECHNOLOGICAL INNOVATION IN THE RESOLUTION OF LOCAL SOCIO-PRODUCTIVE PROBLEMS. CASE STUDY: CONCORDIA, ENTRE RÍOS, ARGENTINA

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INNOVACIÓN TECNOLÓGICA EN LA RESOLUCIÓN DE PROBLEMÁTICAS SOCIO-PRODUCTIVAS LOCALES. CASO DE ESTUDIO: CONCORDIA, ENTRE RÍOS-ARGENTINA

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RESUMEN

El presente trabajo pone en relevancia la promoción del diseño y gestión de innovaciones tecnológicas para la resolución de problemáticas socio-productivas locales. Desde una visión de innovación, que intenta superar la óptica exclusivamente económica, se toma como caso paradigmático una experiencia de producción de hábitat desarrollada en la localidad de Concordia (Entre Ríos, Argentina). La misma, desarrolla colectivamente una tecnología asociada a sistemas constructivos en madera, con el fin de promover procesos productivos sustentables a partir de recursos y saberes locales. Asimismo, propone una innovación que intenta modificar los modos productivos actuales, superando la transferencia tecnológica unidireccional, por nuevas formas de resolución de problemas de manera cooperativa y solidaria. Mediante un estudio interpretativo, el trabajo tiene por objetivo principal analizar el caso desde la perspectiva crítica de la tecnología, relacionando el concepto de *código técnico* (normas cognitivas y sociales que configuran los procesos de producción de conocimiento) con los modos de diseñar y gestionar la producción de hábitat en la experiencia. Como resultado, se dilucidan aspectos emergentes del caso que, a modo de insumos o lineamientos, permiten contribuir a la generación de nuevos abordajes para la producción de un hábitat sustentable y más justo cognitivamente.

Palabras clave
Energía incorporada, emisiones de CO2, residuos de demolición y construcción, diseño por ordenador

ABSTRACT

This paper highlights the promotion of the design and management of technological innovations for the resolution of local socio-productive problems. Working from a point of view on innovation that attempts to overcome an exclusively economic perspective, a habitat production experience carried out in the town of Concordia (Entre Ríos, Argentina) was selected as a paradigmatic case. This experience collectively develops a technology related to wood construction systems in order to promote sustainable production processes based on local resources and knowledge. Likewise, it proposes an innovation that attempts to modify the current modes of production and surpass unidirectional technological transfer with new ways of solving problems cooperatively and charitably. By means of an interpretive study, the main objective is to analyze the case from the critical perspective of technology, relating the concept of technical codes (cognitive and social norms that configure the processes of knowledge production) with the ways of designing and managing habitat production in the experience. As a result, emerging aspects of the case are elucidated, which in the form of inputs or guidelines make it possible to contribute to the creation of new approaches for the production of a sustainable habitat that is more cognitively just.

Keywords
technology, society, construction systems

Innovación tecnológica en la resolución de problemáticas socio-productivas locales. caso de estudio: concordia, Entre Ríos-Argentina
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INTRODUCTION

PRESENTATION OF THE PROBLEM

The search for new approaches for the production of a sustainable and more just cognitive habitat is the main driving force in the present work. For several decades, the Social Studies of Science and Technology (ESCyT, by its initials in Spanish) try to question the role of scientific-technological knowledge in relation to society. Among the different disciplines and theoretical perspectives that make up these studies lies a common criticism: overcoming the classical and deterministic vision of Science and Technology (S&T), where the product is prioritized over any other rationality, assuming that all technological development is the solution to an existing problem without considering particularized contexts or actors. Authors such as Dagnino (2008) consider that this conception leads to a technical and not political issue, which exemplifies from a kind of virtual barrier that is formed between the scientific-technological production environment and the social, political, social and economic context of our societies. In Latin America, issues such as the democratization of knowledge and social inequality are being approached from this theoretical perspective by various institutions and research, whose emphasis is placed on generating a more appropriate management of S&T.

In Argentina, there is still a long way to go in the construction of alternative approaches that generate sustainable processes in the habitat field. But for some years a group of researchers from the National Council of Scientific and Technical Research of the Nation (CONICET, by its initials in Spanish) has been developing technological innovation processes in different places of Argentina. The ideological conviction of these processes is the strengthening of small enterprises, since they contribute to the generation of employment (70% of productive employment is in hands of these enterprises) and the distribution of income that this type of economic process promotes, promoting commercial articulations for supply and consumption within the country (Peyloubet, 2018).

By articulating the habitat problem with the productive processes, the research team has developed technological innovations with locally grown wood, considering the high socio-productive potential that it has. According to Diana Guillén, the characteristics of Argentina place this country among the regions of the world with the greatest natural advantages due to the rapid growth of its plantations and its productive potential (cited in the National Service of Food and Agriculture Health and Quality, 2014).

The city of Concordia in the province of Entre Ríos (case study) has the largest wooded area of Eucalyptus Grandis. As a local problem, it is noted that the main destination of this production is sawing (45%), predominantly small industries that use short wood and produce packaging, pallets and drawers. The remaining percentage (55%) is considered a byproduct: sawdust, beams, bark and refile for the manufacture of chipboard. In this scenario, local processes that provide added value and income distribution over that remaining 45% are not identified.

Faced with this socio-productive problem, it is worth asking: How to design and manage technological proposals that contribute to the improvement of local territories? How to proceed to other alternative operations that give rise to new codes or technological standards that are more appropriate socially and technically?

Following Albornoz (2013), innovation is today at the center of the policies that Latin American countries apply to boost development and equity. However, there was a mimetic translation of policies created in economies where there is a strong demand for new knowledge in economic contexts in which such demand is very low (Albornoz, 2013). Likewise, innovation is frequently used to influence the competitiveness of companies and very little to relate it to the improvement of social problems (OEI, 2014).

Another question that is given to technological innovation processes are the traditional ways in which knowledge is legitimated and constructed in these processes. For Santos (2009), there is an attempt to dismantle the existing dichotomy between expert or scientific knowledge and local or popular knowledge with the aim of rescuing knowledge that arises from social experiences themselves.

Within this framework, the main objective of the work is to understand and interpret the particularities that were given in a technological development process, which links the S&T sector with the territory. Methodologically, the case is analyzed from the critical perspective of technology, relating the concept of *technical code* (cognitive and social norms that configure the processes of knowledge production) with the ways of designing and managing habitat production in the experience. For this, a series of starting budgets and *ad hoc* analytical categories were developed; the latter recognized in the present work as the design premises the research team uses in its research work. Regarding results, emergent aspects of the case were elucidated, which as inputs or guidelines are intended to contribute to the generation of new approaches for the production of a sustainable and more just cognitive habitat.

THEORETICAL AND CONCEPTUAL FRAMEWORK

Throughout history, the processes of industrialization and technological development have been continuously accompanied by counter-currents of innovation, as a reaction and questioning of the dominant trajectories from the development of different movements (denominated as Appropriate Technology and Social Technology) with forms

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of alternative and socially inclusive innovation (Fressoli, Smith, Thomas and Bortz, 2016).

For the present work, it is important to highlight Social Technology as a contemporary innovation movement that seeks to provide a new way to develop and implement technologies (of Product, Process and Management) oriented to the generation of dynamics of socioeconomic inclusion and sustainable development (Thomas and Becerra, 2014). This movement provides a procedural dimension, an ideological vision and a different operational element that is not found in current available technologies (Dagnino, 2008).

The integration of theoretical concepts and ideological conceptions from different disciplinary approaches (philosophy of technology; sociology of technology; economics of technological change, etc.) constitute the analytical-conceptual framework with which the study of Social Technology is approached based on a critical review of the so-called Appropriate Technology (AT), with the objective that from there another different cognitive-based technology can be built.

The criticism pointed to this technology (AT), originated in the 60s, is based on the idea that the solution to the problem is built in an unidirectional way generating a game of supply and demand, where the transfer logic subordinates all the process. This means that a series of technologies have been developed as *stock*, used many times according to demand, and that it has mainly left aside that traditional or tacit knowledge, which the academy does not legitimize. Thus, the high potential of knowledge contained in actors and social experiences is wasted, warning that knowledge is still built exclusively from top to bottom, from a unidirectional process, that is, as transfer.

Therefore, we consider that, in the search for alternatives for habitat production, Social Technology represents a path that goes in that direction. Among the theoretical models that make up these studies, Social Constructivism and Critical Theory of Technology constitute a radical response to the mono-dimensional, linear and deterministic view of technology. Regarding Social Constructivism, Valderrama (2004) describes this theory as a way to open the black box of knowledge to discover that inside there are dynamics that must be studied because they are closely linked to social processes. This theory offers the possibility of considering technology as a social construction and as a result of negotiation processes and different interpretations between relevant social groups, until technology becomes what finally is. However, we believe that it is not enough to open the black box and identify the relevant actors and their interests, but it is also necessary that, prior to the design of technologies, more democratic mechanisms operate. In that sense, Andrew Feenberg's proposal revolves around the extension of the value of democracy to the field of technology. The author suggests that the notion of rationalization, today focused on the idea of progress and efficiency, should be based on the responsibility of technical action by human and natural contexts. For this, Feenberg (2006) proposes to change the dominant values of technological rationality, incorporating a priori in the design of technology, alternative social, cultural and environmental aspects, which favor more participatory and democratic forms. It also refers to the notion of technical code as to the realization of an interest in the form of a technically coherent solution to a problem. That is, "the product of technical elections supports the way of life of one or another influential social group" (Giuliano, 2012, p. 2). In most cases, the interests of dominant groups are materialized in technical codes that, invisibly, settle into rules, procedures, instruments and artifacts for the search for power and advantages for a dominant hegemony. For Feenberg, the characteristics of this technical code are authoritarian, top-down and pose serious problems, even in the most advanced sectors of society (Tula Molina and Giuliano, 2015). This approach makes it possible to see more clearly that in technological designs there are beneficiaries and victims, so its concretization represents a series of struggles and strategies among various actors to develop one or another technological alternative. According to Feenberg (2006), technology can constrict and colonize, but it can also release repressed potentials from the world of life that would otherwise have been submerged. Therefore, for this theorist, technology is essentially ambivalent and available for various types of development. In addition, authors such as Tula Molina and Giuliano (2017) argue that other aspects such as interests, customs, values and power relations are involved in the design of technology, so it is necessary that they are under discussion by a plurality of social actors, not just experts, and organized based on democratic principles.

METHODOLOGY

The present work is positioned within the framework of the Interpretative paradigm[1], whose "foundation lies in the need to understand the meaning of social action in the context of the world of life and from the perspective of participants" (Vasilachis, 2006, p. 48). A research positioned from this paradigm considers that the case itself plays a fundamental role, which can contribute to the understanding of the problem under study. (Kazez, 2009).

[1] According to Guba and Lincoln (1994) in the interpretative paradigm there are multiple, holistic and constructed realities. This implies the renunciation of the positivist ideal of prediction and control.

Following that line, the purpose of the research presented here is to understand and elucidate deeply a particular case of habitat production (Concordia, Entre Ríos). First, it is interesting to address this case from the qualitative tradition, mainly due to two specific characteristics: a) for what this tradition studies: contexts, processes, senses, meanings and stories; and b) for the goal and its purpose: search for the new and provision of new perspectives on what is known, described, explained, elucidated, constructed and discovered (Vasilachis, 2006).

In this context, it is proposed to analyze the case from the critical perspective of technology, relating the concept of *technical code* with the ways of designing and managing habitat production in the experience. Thus, "technical code" is understood as those cognitive and social norms that configure the processes of knowledge production and whose result determines a type of technological innovation. This approach allows us to clearly appreciate that in technological designs there are benefited and affected, so that the concretization represents a series of struggles and strategies among diverse actors to develop one or another technological alternative. From this critical view about technology, a series of starting budgets that guided the current reflection are enunciated:

- Local knowledge constitutes indispensable inputs to produce transformations capable of improving people's quality of life, making them compatible with the natural and social context.
- In most technological innovations, within the field of habitat, traditionally used knowledge (local knowledge) is not incorporated and the product or technological device is privileged over technological processes or managements.
- The application of democratic management models enables the empowerment of actors and sectors often invisible in habitat production processes.

Consequently, in the search to elucidate emerging inputs for the generation of a sustainable and more just cognitive habitat, the study of the case from three analytical categories elaborated in this sense is proposed as a methodological strategy:

a) Application context (assessment of installed capacity). This analytical category refers to the production of knowledge and its relation to its social utility. This intention of producing knowledge that is useful for someone, whether the productive sector, local governments or society in general, is reflected in a relevant way from the beginning of the interventions or investigations. Therefore, this category allows us to analyze the context of application of the case, what are the capacities assessed and rescued for habitat production and to which specific sectors of society benefits.

b) Productive meetings: Co-construction of knowledge (collective knowledge production). This analytical category is a research premise the research team has been developing for several years in habitat production processes. The co-construction of knowledge ascribes to a type of collective work, where knowledge of various actors is incorporated into productive processes. It allows analyzing what kind of knowledge circulates in these spaces called "productive meetings", how these spaces are built and what meaning is given to the intellectual property of the results obtained.

c) Inter-actor/inter-sector alliances (democratic management). As a research premise, this category assumes management as an active inter-sector articulation, whose strategy is to convene in the resolution of the habitat problem to the largest number of relevant sectors for the definition of public policies that generate distributed benefits. This allows the analysis of the agreements arising from this type of management, how information is shared, how the senses and interests of each participating sector converge and how decisions are made.

Case study characterization: The experience takes place in the city of Concordia (province of Entre Ríos), located on the Argentine coast (Figure 1). As the second largest city in that province, it is characterized by the relevance of forestry activity, as it has the largest area of Eucalyptus Grandis trees. Since 2010, a group of CONICET researchers has implemented in this town (through various research projects) an Inter-Actor Network with the aim of carrying out technological developments in wood, putting in value from its beginning the local productive matrix (Peyloubet, 2017) (Figure 2). In this context of application and under a process of cognitive innovation, a timber construction technology has been specifically developed that, due to its component configuration, has a flexible design and adaptable to different uses (housing, urban equipment, recycling plants, etc.). By means of this proposal, it is tried to drive the forestry-industrial production of the region and locality in order to promote the labor potential in the sector, making efficient use of the wood resource and diversifying it to reach higher profitability levels, and thus generate on the value chain a surplus in the use of the raw material from the product design (construction system). Similarly, it is noted that the proposal involves small producers that are part of the vulnerable economy of the locality, whose insertion in the market requires a leverage of the State.

DISCUSSION AND RESULTS

A) APPLICATION CONTEXT: INSTALLED CAPACITY ASSESSMENT

The experience in Concordia is characterized by a mode of production of alternative knowledge to traditional or hegemonic mechanisms. The CONICET research team has been developing habitat production processes in other

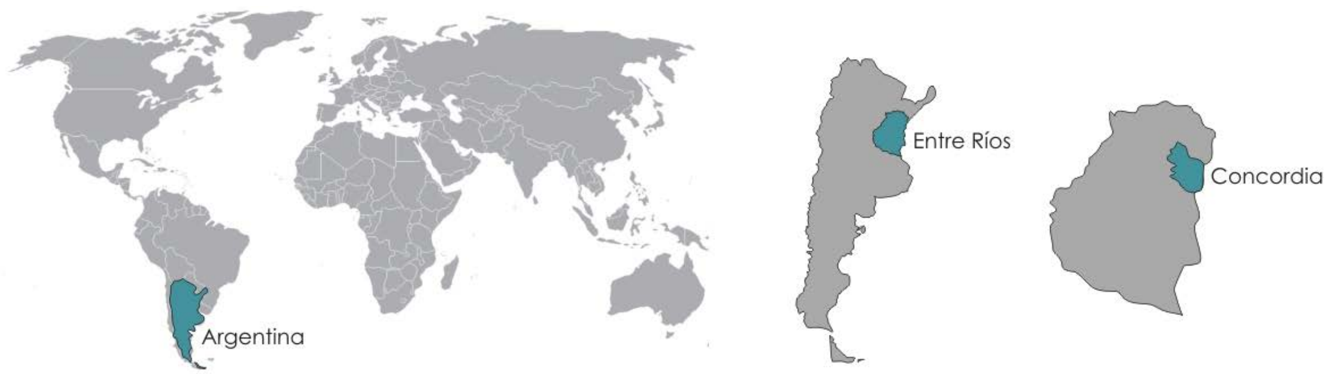

Figure 1. Geographic location. Source: Author's elaboration.

Figure 2. Forest production. Sawn wood of Eucalytus Grandis. Source: Image extracted from PROCODAS (2011) and PAD-ANPCYT (2017).

locations where the resolution of the problem has been generated from inter-actor productive circuits and not from the conception of the device, that is, housing. This alternative way of addressing habitat production called the interest of municipal officials in Concordia and in 2010 the research team was convened by the Ministry of Production and Labor to work on projects that will boost local productive chains in the forestry sector, production of housing and work generation for small producers. In that context, Concordia had an important installed capacity: Eucalyptus forests, sawmills and a Carpenters Association.

Faced with this under-utilization of local resources and knowledge, the intervention proposal in the territory was developed under the following design premises:

a) Recognize and value the local productive matrix: sawmills and forests were visited with the objective of highlighting installed capacity (Figure 3).

b) Based on this recognition and assessment use the highest possible percentage of local wood (Eucalyptus Grandis) for the construction of components: this would allow to re-diversify and re-signify in the population the use made of wood resource in the locality[2].

c) From a local demand, it is decided to design a multipurpose room (SUM, by its initials in Spanish) as a pilot prototype, with a construction system made predominantly of 1"x4" Eucalyptus Grandis boards, recognized as the local productive matrix (Figure 4).

[2] At this point, it is key to clarify that the choice to decide to use the local productive matrix (wooden boards of very small section) to redefine the use of Eucalyptus Grandis wood, generated the development of a particular structural design able to respond primarily to the request of wind efforts. In this sense, it was necessary to subject this design to rigorous structural calculations, being formed a structure of porches (enclosure panels), columns and a roof structure. As a result of these calculations, the dimensions of the system elements, the placement of diagonals to generate rigidity to the structure, the amount and type of metal linkages, etc. were determined.

Figure 3. Tour of local forest productions. Source: Images extracted from DETEM (2012).

Figure 4. Design and technological development of a SUM with local wood. Source: Images extracted from PID 0079 (2016).

Figure 5. Construction system of prefabricated components that adapts to different types such as housing or neighborhood equipment. Source: Images extracted from PID 0079 (2016).

d) Design a technological development of flexible product capable of adapting to different requirements and uses: housing or neighborhood equipment (Figure 5).

Likewise, the choice of a renewable natural resource such as Eucalyptus wood for construction meant that several dimensions of the problem were explored profitably: in environmental terms, a fast-growing forest wood resource was being used which, when selected as construction material had significant comparative advantages in relation to other construction materials, among which the following stand out:

- Wood production acts as a carbon store purifying the air and contributing to the reduction of the greenhouse effect;
- Wood production and transformation processes consume less energy than the production processes of other materials;
- Much of the energy consumed comes from its own waste therefore the industrialization of wood has a positive impact on reducing the demand for solid fuels;
- Wood ashes can be used as fertilizers for the field.

Decisions and elections made collectively at the beginning of the research project sought to support the interests of the local productive sector and respond to the demand of the government sector (local municipality), whose purpose was to revitalize the local economy. That is, this constitutes a proposal for habitat production that responds to local needs, and not vice versa, as when the community has to adjust to the new technology introduced (dominant process in the construction of technologies). Following Herrera (2010), it is very frequent the detection of proposals and technological developments focused on product innovation that, in general, dismiss, in a previous way, all the social and technical conditions local actors can provide to the construction of such technology. The fact that the project revalued the trade and local capacity in the city of Concordia made the actors work, from their identity;

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Figure 6. Potential place of knowledge production, called as Productive Meetings. Source: Images extracted from PID 0079 (2016).

basically, from what they are and know how to do, creating a social subject that can modify and appropriate the technological product based on their experience in the trade (generation of autonomous work). In that direction, the search for added value to a sub-utilized resource and the recognition of the installed capacity in the locality constitute one of the elements that configure cognitive and social norms that govern the process of knowledge production in the experience in Concordia.

B) PRODUCTIVE MEETINGS: CO-CONSTRUCTION OF KNOWLEDGE (COLLECTIVE KNOWLEDGE PRODUCTION).

The methodological proposal of a habitat production approach that this experience poses assigns, as it has been sustained, to a type of collective work where knowledge of different actors is incorporated into the productive processes, in an integration that allows to open the black boxes of the expert knowledge of some and claim the technical and experiential knowledge of others. This methodology was called by the research team as "Co-construction of knowledge". According to Peyloubet (2018), the fundamental idea in collaborative work proposals such as this one is based on complementarity, which displaces competitiveness, in an associative action, where intellectual property is shared. In this way, the development of constructive technology, that is to say of product, is created in spaces of interaction called "productive meetings" where, in a group way and through respectful participation, ideas, knowledge and technical decisions about technology in question are expressed. For the participating actors - carpenters, researchers, municipal technicians, working cooperatives - these meetings are spaces where wisdom and knowledge circulate in solidarity and where everyone teaches and everyone learns, resulting in a collective construction of technology. In that sense, the paradigmatic and beneficial experience is that technological development did not reach the town as a closed system, as a black box and together with a user manual, but quite the opposite. The predisposition of the research technicians to exchange knowledge was present when they arrived at the Carpenters Association of Concord. The decision not to transfer technologies through a dialogic approach with the actors involved implicitly gave the technology political qualities, such as:

- The possibility of actors involved to feel part of the development of technology;
- The possibility of change, adjustments and new ideas from the exchange;
- The enrichment of all actors involved, including the academic sector itself, thanks to the exchange of different knowledge that generated new learning;
- Openness to problems and local reality, which made it possible for technology to be the most appropriate socially and technically to that context.

The strong recognition of the local, and the use of a methodology of work of Productive Meetings, promoted another transition instance in the ways of operating of the S&T sector. Once the SUM was assembled and built, and after the start of the construction of the first home as a prototype, the need to manage a Technical Aptitude Certificate of the system was collectively noted[3] (CAT, by its initials in Spanish). For the research team, the construction system that had been reached was the result of the integration of ideas, knowledge and solutions that the community had traditionally used

[3] CAT: Technical proficiency certification of non-traditional built systems such as wood required for construction with national funds.

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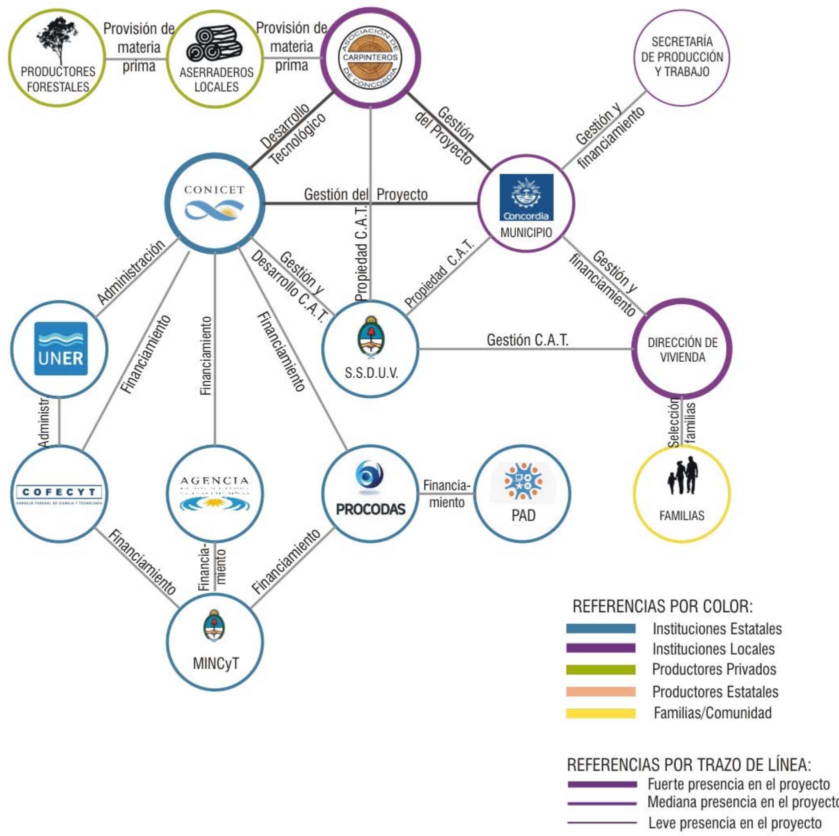

Figure 7. Inter-actor network of experience in Concordia. Source: https://coconstrucciondelconocimiento.wordpress.com

in the construction of wooden houses (product), as well as aspects of management and commercialization of local resources (process). Therefore, it was decided to leave it in the hands of the municipal actor and the Carpenters Association. A technology whose final resolution was the product of a complementarity of diverse knowledge could not be limited by patents involving lucrative rights for the alleged developers, technologists, researchers, among other participants. That is to say, there is not an actor, a *hero* behind that technology, but there are several actors that can change and, in addition, can continuously adapt the technology, without it depending on someone in particular or exclusively. In this context, the collective decision about requesting CAT of technological development meant for the experience a way to decentralize conventional housing policy and replace it by a new way of managing housing policy from a local municipality.

C)INTER-ACTOR/ INTER-SECTOR ALLIANCES (DEMOCRATIC MANAGEMENT)

Another key element of technological innovation in the experience shared here is the inter-actor and inter-sector articulation as a cognitive and social norm of knowledge production. The purpose of this strategy is to convene the resolution of the habitat problem to the largest number of relevant sectors that can contribute to the definition of public policies aimed at generating distributed benefits. In that line, for the research team the sectors that must be present are:

1. State sector: as guardians of the common good;
2. Productive sector: entrepreneurs in the value chain; and
3. Cognitive sector: mediators of diverse knowledge.

In the experience, the participation table was made up of the following sectors: representatives of the municipality (Land and Housing Institute, Sub Secretariat of Economic Development), representatives of the productive sector (Forest Producers, Sawmills, Labor Cooperatives, Carpenters Associations) and representatives of the cognitive sector (Universities, Research Centers and Agencies); who in successive deliberations were building agreements to innovate in the productive processes affecting the three sectors trying to promote the work with autonomy and the co-resolution of local problems (Figure 7).

The financing instruments that support this type of technology come from the Science and Technology sector, since the promoter and mediator group is made up of researchers (cognitive sector). It should be clarified that the proposal of the Inter-Network has had

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Figure 8. Inter-sector alliances/policy articulation. Source: Images extracted from PROCODAS (2011; 2017).

the support and approval of financing projects in that sector during almost ten years of its existence, since the key aspects of this proposal are relevant because they are instruments of a scientific-technology policy established by the Innovative Argentina 2020 Plan. The initiative had five research projects funded by the National Agency for Scientific and Technological Promotion. The continuity of the financing instruments in the experience was key, since they allowed us to move forward with the objectives set and it generated in the participating actors the motivation to continue being part of the Inter-actor Network.

The methodological and ideological premise of generating a democratic management model was essential for the project. The successive meetings with each representative of sectors allowed for an exhaustive information, a deep understanding and a democratic decision of aspects and issues that have to do with the development of technology (Peyloubet, 2018).

One aspect to note was that the various meetings in the municipality with the mayor and officials always had the presence of producers of technological development (Carpenters and Cooperatives Association). In that sense, the project always sought the empowerment of sectors, often silenced when making decisions. This strategy gave way, to the interior of groups or associations, to a great availability of information and proposals to be able to take control of their work and to notice problems, solutions and new opportunities related to their ways of working. A democratic process was thus generated where everyone positioned themselves as co-participants and co-responsible for the ongoing project(s). This way of managing technology, which refers to the presence of all the actors, without establishing hierarchies, encouraged the construction of a network of external relations at national and regional level, where organizations, and particularly, the Carpenters Association, achieved establish contacts and relevant information, as well as proposals for new work. The link and alliances generated within the framework of the Network allowed a new way of participation in the resolution of socio-productive problems, where (in this case) the State (municipal government) represented the interests of smaller groups or economies, creating job opportunities and access to resources, within the framework of collective and democratic decisions (Figure 8). In this way, the Carpenters Association accessed and managed new benefits outside the project under study, among which are:

1) Capitalization in infrastructure: through the Ministry of Social Development of the Nation they obtained a machimbradora[4];
2) Sale of wooden components for the local municipality (doors and shelters for lifeguards in wood to be placed on the banks of Paraná River);
3) New Wooden Healthy Stations for the town;
4) Training in the framework of projects of the Ministry of Labor and Production;
5) Agreement with the Ministry of Social Development of the Nation for the production of structural components of roof (wood), for a waste treatment plant in the town of Concordia.

[4] Machimbradora: Machine used in carpentry to make in sawn boards moldings or inserts (machimbre).

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CONCLUSIONS

The proposal presented here has been carried out successfully since 2010, and it has been possible mainly - from what the participants themselves attribute - to the trust built between the different members that make up the socio-productive network. On one hand, the theoretical and ideological conviction of the research group is expressed year after year in the formulation and presentation of new projects in the Ministry of Science and Technology of the Nation; institution that approves and continues to support this type of technological development through its different financing lines. On the other hand, the carpenters of the Association, as the main productive actor, continue betting on generating new paths and new processes that promote benefits distributed in their locality. And a municipality, which although at the beginning of the project was very present and then not so much, never stopped leveraging and supporting the research proposal.

Faced with this scenario, three key aspects of technological innovation that the experience in Concordia carried out to address habitat-related issues can be highlighted as conclusion:

- *Local socio-productive technological developments:* The initiative is based on an approach that allows us to fully understand and take advantage of the opportunities offered by the local productive network, developing proposals that seek to strengthen and diversify new forms and production processes to generate re-distributive economic dynamics. In the case of the study experience, the research team warned of a sub-utilization of natural resources (renewable-wood), as well as local productive capacities being considered as new emerging opportunities.

- *Collaborative and Associative Technological Developments*: the methodology that implements the proposal ascribes to a type of collective work, where knowledge of the various actors are incorporated into productive processes, in an integration that manages to open the "black boxes" of the customary knowledge of some and enhance the technical and experiential knowledge of others. The co-construction proposal constitutes one of the most relevant research elements of the CONICET team, which forces us to conceive technological developments as a cognitive heritage of a group of entrepreneurs that are organized in a social economy based on the distribution of income and socio-productive inclusion, promoting a more supportive market. This co-construction is fundamentally manifested in what the research team calls *Productive Meetings* where, in a group way and in a respectful participation, ideas and technical decisions that will give birth to the technological product are agreed.

- *Inter-sector Technological Developments:* The approach to building a fairer and more sustainable habitat is based on the articulation of various actors and sectors that, from their different positions and interests, promote agreements arising from an exhaustive information and a democratic decision. For the proposal under study, the presence of State actors (guardians of the common good), productive actors (entrepreneurs in the value chain) and cognitive actors (mediators of diverse knowledge) is a relevant aspect for the promotion of new public policies in the field of habitat production.

Thus, the cognitive and social norms that govern the process of design and development of technology in the experience are based on aspects such as: a) technological developments that impact as little as possible on the environment (use of renewable resources); b) developments that leverage small and vulnerable economies; c) developments that promote associative and cooperative forms of production; d) developments that generate fair distribution of income; and, e) developments that co-design a collective property product.

Consequently, thinking of technological development processes from this approach represents an invitation to address the problem of habitat from a systemic construction, since the social, cultural, economic and environmental dimension is at the same level of hierarchy and the technological product constitutes an excuse to energize and democratize technological processes. Likewise, it allows the problem to be approached from a political perspective, assuming that power provisions are specified in technology, registered in technological developments from the premises with which they were designed. This approach also provides the opportunity to become aware of the importance of the way in which technical decisions and choices influence technological processes and the need for critical awareness about conventional ways of making technology. This leads to assume the relevance of reflexive instances, capable of being carried out by managers, technicians, professionals, academics, etc., resulting in the development of proposals in territories with a view to increasing options to proceed to other alternative operations in the habitat field.

Based on the results obtained, it can be noted that when socio-productive problems are faced in a joint, participatory manner and from its genesis, a technology of political qualities with differentiated cognitive and social norms of knowledge production would be developed. The possibility of generating a technological process where the problem is co-built, and in an inter-actor manner, allows the circulation and sharing of local knowledge and solutions that are typical of the relevant sectors of a given territory.

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From that point of view, the experience in Concordia represents an opportunity to be immersed in a complex deconstruction process and then reconstruct a technology that allows solving socio-productive problems from *a socio-productive, solidarity, cooperative and inter-sector technological* approach. This work, in short, constitutes an opportunity to continue wondering where and how the development of a technology capable of configuring a fairer and more sustainable habitat should be directed.

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