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[EU] Habitatea zaintzea / Zaintzeko habitatea

Eraginkortasun Energetikoa eta Jasangarritasunaren inguruko Arkitektura eta Hirigintzaren 14. Biltzar Internazionalak (EESAP 14), «HABITATAREN zaintza/HABITATA zaintzarako» gaia landuko dute, HABITATA eskala guztietan ulertuta; lurralde- eta hiri-eskalatik eraikuntza-eskalaraino. Ikuspegi bikoitz horrek honako hau zalantzan jartzea dakar: nola zaintzen da edo zer behar da habitat hori zaintzeko? Nolakoa izan behar du habitat horrek gure zaintzarako eta pertsonen bizi-kalitatea bermatzeko?
Eztabaida berri honen aurrean, gure ohiko kolaboratzaileak eta biltzarraren hamalaugarren edizioan parte hartu nahi luken oro gonbidatzen ditugu beren proposamenak aurkeztera. Aurreko edizioetan bezala eta bere alderdi akademikoan oinarrituta, biltzarra bereziki ikasle, profesional eta ikertzaileei zuzenduta dago.
EESAP8/CICA1 ediziotik,zientzia eta teknikaren zabaltze-eremua eraikuntza berrikuntzetara zabaldu da eta baita enpresa mundura ere, enpresa berrikuntzak indartzeko dauden gizarte beharrei erantzuna emateko, eta era berean, horiek hiritar guztien bizi kalitate maximoa lortzeko bidean jartzeko.
Antolakuntza batzordeak, CAVIAR ikerketa taldeak (Arkitekturako Bizi Kalitatea, UPV/EHU) osatua, gaurkotasuna duten eta berritzaileak diren gaiak lantzen dituen antolaketa baten aldeko apustua egin du. Espazioa honetan, horrela, adituek, ikertzaileek, ikasleek eta enpresek elkar eragiteko, ezagutzak trukatzeko eta sarea sortzeko aukera izango dute, habitataren eskala bakoitzerako bi eguneko eta lau gaikako blokeko programa baten bidez. Programa horretan hitzaldi magistralak, mahai-inguruak, komunikazio libreak eta workshop-ak sartzen dira.

[EN] Care for the habitat / Habitat for Care

The fourteenth edition of the International Conference on Energy Efficiency and Sustainability in Architecture and Urbanism (EESAP 14) will address the theme of “Care for the HABITAT/HABITAT for care”, understanding HABITAT in all its scales; from the territorial, the urban to even the building scale. This double approach implies rethinking the following: how do we take care of or what is needed to take care of this habitat? How should this habitat be for our care, and to guarantee the quality of life of people?
In the light of this new debate, we invite all our regulars and those who want to join us in the thirteenth edition of our conference to present their proposals. As in the previous editions and given in its academic facet, the conference is especially aimed at professionals, researchers and students.
Since the EESAP8/CICA1 edition, the conference has extended the scope of scientific and technical diffusion to the entire innovative construction sector. Furthermore, it is opened to the business sector, due to their close relationship to meet current social demands on business innovation for achieving a higher quality of life.
Once again, the Organising Committee, CAVIAR Research Group (Spanish abbreviations for Quality of Life in Architecture, UPV/EHU), has opted for innovative and current interest subjects to promote an atmosphere in which professionals, researchers, students and companies will be able to interact. exchange knowledge and create network through a two-day programme with four thematic blocks for each of the habitat scales that includes lectures, round-tables, research communications and collaborative innovation workshops (networking).

[ES] Cuidado para el hábitat / Hábitat para el cuidado

La decimocuarta edición del Congreso Internacional sobre Eficiencia Energética y Sostenibilidad en Arquitectura y Urbanismo (EESAP 14) abordará el tema de «Cuidado para el HÁBITAT/HÁBITAT para el cuidado», entendiendo HÁBITAT en todas sus escalas; desde la territorial, la urbana y hasta la edificatoria. Este doble enfoque implica que nos cuestionemos lo siguiente: ¿cómo se cuida o qué se necesita para el cuidado de ese hábitat?, ¿cómo debe ser ese hábitat para nuestro cuidado y garantizar la calidad de vida de las personas?
Ante este nuevo debate, invitamos a todos nuestros habituales y a quienes quieran acompañarnos en la próxima edición de nuestro congreso a exponer sus propuestas. Como en las anteriores ediciones y dada su faceta I+-D+i+t, el congreso se dirige especialmente a profesionales, investigadores y estudiantes.
Desde la edición EESAP8/CICA1, el congreso amplía el ámbito de la difusión científica y técnica al conjunto de la innovación en la construcción y se abre al mundo empresarial, con el que se vincula para atender a la demanda social de fortalecer la innovación empresarial y encauzarla hacia la consecución de la máxima calidad de vida para todos los ciudadanos.
El comité organizador, compuesto por el grupo de investigación CAVIAR (Calidad de Vida en Arquitectura, UPV/EHU) apuesta, como siempre, por un recorrido a través de los temas actuales y novedosos, en un espacio en el que, profesionales, investigadores, estudiantes y empresas pueden interactuar e intercambiar conocimientos y crear red, a través de un programa de dos días y cuatro bloques temáticos para cada una de las escalas del hábitat que incluye conferencias magistrales, mesas redondas, comunicaciones libres y workshops.

First day schedule, October 4th, Wednesday

Second day schedule, October 5th, Thursday

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Bridging the gap between urban studies and tourism: a review of urban fabric elements and the negative impacts of tourism

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Key Words: Urban tourism, Urban fabric, Negative impact, Sustainable strategies.

0.ABSTRACT

In recent decades, urban tourism has experienced significant growth, leading to notable changes in the urban landscape and impacting both tourists and residents. Although several studies have explored the positive aspects of urban tourism, there is an urgent need to examine the negative effects of its uncontrolled presence and its actions aimed solely at attracting more visitors. Moreover, although they are identified as necessary, only a limited number of studies have adopted a holistic approach to manage urban planning policies.

This research argues that the urban fabric plays a crucial role in shaping the tourism experience. Understanding its relationship with tourist dynamics is essential to identify vulnerable areas where negative effects may arise. Through a literature review of relevant research articles published between 2010 and 2023, the research presents the latest perspectives on the role that plays the city and its elements as a tourist destination and how the negative impacts of tourism affect the components of the urban fabric. Ultimately, this study highlights the need for sustainable and responsible tourism practices and emphasizes the importance of urban planning in tourism management. The paper aims to encourage stakeholders to adopt a comprehensive and integrated approach to urban tourism planning from a holistic perspective that promotes the resilience of European cities.

1. INTRODUCTION

The relationship between cities and tourism is undeniably strong, as cities serve as key destinations for tourists worldwide. However, despite this close connection, a theoretical gap hinders the integration of urban studies and the tourism industry. This article seeks to bridge this gap by exploring literature related to the significance of cities as tourism destinations and the role played by urban fabric elements in shaping the impact of urban tourism. This study aims to address two pivotal questions: How is the relationship between urban fabric and the dynamics of urban tourism and what negative effects in the physical dimensions affect the components of the urban fabric. To answer these interrogations, a literature review is conducted considering peer-reviewed sources on theoretical frameworks, adverse effects, and sustainable approaches related to the urban fabric and tourism impact in European cities.

The paper is organized as follows: first, a section about the literature background on the role of the city as a key attraction and an identification of the components of the urban fabric from a pedestrian scale is conducted, followed by a description of the methodological approach used in the study. Next, the results of the discussion of the negative physical effects of tourism on the urban fabric are presented. Finally, implications for further research are highlighted and conclusions are presented. By examining the significance of the urban fabric as a setting for tourism development, assessing the negative impacts of urban tourism, and exploring best practices, this article aims to contribute to the body of knowledge on urban studies and tourism management.

2. LITERATURE BACKGROUND

2.1 The Evolving Role of the City as a Key Attraction in Urban Tourism

Over the years, cities have played a significant role as epicenters of civilization, housing architectural wonders, cultural heritage, and historical landmarks. Their historical and contemporary significance as desired destinations have positioned them as centers of socio-cultural, economic, and political importance, attracting visitors from far and wide. This convergence of activities characterizes urban destinations as vibrant and dynamic hubs where diverse sectors coexist and interact. Fast forward to the contemporary era, cities continue to play a pivotal role as primary attractions that offer a vibrant blend of experience, entertainment and culture. From iconic landmarks to narrow and unique streets (see Figure 1), cities have become synonymous with excitement, diversity, and a scenario where the past and present coexist [1].

Fig. 1 Photograph of the Eifel Tower in Paris and Bruges' canals. Source: The Authors.

The evolution of cities as main tourist destinations can be attributed to several factors that have redefined the urban landscape, such as globalization, the emergence of the internet and the rise of low-cost airlines [2]. Additionally, cities have embraced the concept of "place branding," strategically positioning themselves as distinctive destinations with their own unique identities and attractions [3]. This has transformed urban areas into melting pots where tourists become temporal residents and coexists with locals in both spatial and temporal dimensions. Nevertheless, it is important to consider that this relatively disrupted transformation comes with a price and creates permanent changes in the urban morphology and people's sense of place [4]. As cities adapt to the new needs of individuals who actively participate in an unfamiliar urban scenery, it becomes crucial to study the interplay between tourism growth, urban transformations and local needs [5], [6].

2.2 The Urban Fabric as a Dynamic Scenario for Tourism Development

As introduced earlier in section 2.1, cities are not merely backdrops for tourism activities; they are dynamic entities with unique character and tourism is deeply intertwined with this urban context [7] [8]. To fully understand and analyze tourism as a transformative phenomenon, it is essential to recognize the importance of the context in which it takes place. Adopting a holistic perspective can help identify key elements of the urban fabric that make up opportunities and challenges associated with urban tourism [9].

It can be argued that the urban landscape, particularly tourist areas, is a shared space in which diverse groups of city users coexist and compete for the same resources. To understand the dynamics of urban tourism, the evolving nature of cities must be considered and new theoretical insights from the field of urban studies should be incorporated. Existing literature emphasizes the importance of analyzing the components of the urban fabric to identify possible vulnerable areas and assess adverse effects associated with the growth of urban tourism [5], [10] [11]. Therefore, the analysis and recognition of urban components play a crucial role in the configuration of tourism consumption patterns.
The urban fabric encompasses the physical layout that shapes the urban environment, including the overall patterns that emerge from the interplay between buildings, parcels, streets and sites [12]. This layout plays a vital role in shaping the distribution, concentration, and value of diverse socio-economic forces related to urban tourism. Levy holds the view that the urban fabric follows a particular logic, with certain categories remaining constant and rules of transformation over time, these are the plot, the street, the constructed space and the open space [13].
Since tourism is a highly socioeconomic and cultural activity, visitors mainly move around in public spaces and iconic locations. Hence, identifying its components must respond to a reduced scale where an eye-level perspective is prioritized [14]. This approach provides a holistic perspective to analyze the complex relationships between tourists, locals, and the physical environment. Examining the details allows for a more nuanced understanding of how tourism impacts the urban environment and its elements, both positively and negatively.
Drawing on urban studies literature that identifies the fundamental elements of the urban fabric and acknowledging the locales where tourism dynamics unfold [7] [9], a classification is proposed where the main elements of the urban fabric are identified (Table 1), this categorization recognizes components where there is a coexistence between visitors and locals and identifies areas of tourist interest [14]. By the identification of areas where visitors and locals interact, this framework underscores the need to consider the diverse needs and perceptions of both groups in the planning and management of urban spaces.

Table 1 Urban Fabric components and elements. Source: Authors

Component	**Key elements**
Transportation Network	Streets Sidewalks Bike lanes Pedestrian streets
Public/open spaces	Parks Plazas Public markets Playground Waterfronts Promenades
Infrastructure	Water supply Sewage treatment Power distribution Telecommunication
Transportation systems	Buses, metro and tram Vehicles Bikes Scooters Stations
Landmarks	Cultural institution Historical Buildings Monuments
Buildings	Residential, commercial, industrial, and institutional structures

Many scholars claim that transportation networks, public spaces and landmarks play an important role in creating a sense of place for residents and serving as major centers of attraction for visitors [15]. However, the influence ratio of tourism transcends these elements [16] since in the city the boundaries between visitors and residents are blurred, especially when there is a juxtaposition between infrastructures and services that were not designed primarily for tourism use, so it is necessary to consider the components related to buildings and infrastructure that house tourism-oriented businesses since their analysis contributes to the recognition of new tourism nodes. This reality between the elements of the urban fabric and tourism-oriented uses highlights a critical asymmetry, in which the tourism industry depends on cities while the dependence of cities on tourism remains uncertain [5].

3. OBJECTIVE AND METHODOLOGICAL APPROACH

This paper aims to provide a deeper understanding of the relationship between the urban fabric and the tourism industry in European cities by providing a theoretical framework that complements and expands the existing theories regarding the impact of tourism and the existing urban elements that shape the city. It intends to start bridging the existing gap in urban planning and tourism studies by exploring the relationship between tourism and the city from a holistic perspective at an eye-level scale and shed light on sustainable strategies in the management of contemporary urban tourism.
By conducting a comprehensive literature review, this study delves into peer-reviewed sources published on Scopus databases that explore theoretical frameworks that address the interaction between urban fabric elements and the negative impact of tourism, using the following search string on the title, abstract and keyword: TITLE-ABS-KEY ((“urban fabric” OR “built fabric” OR “city”) AND (“city tourism” OR “urban tourism” OR “cultural tourism”) AND (“negative impact*” OR “ negative effect*”)). The inclusion criteria involve a theoretical framework that specifically addresses the relevance of the urban fabric and the emergence of urban tourism effects, focusing on the physical dimension due to the prevalence of social descriptive studies in the literature [1]. To delimit the scope, papers related to coastal and rural tourism, as well as destinations outside the European context, were excluded and a time lapse between the years 2010 and 2023 is applied.

4. FINDINGS

4.1 Assessing the Negative Impact of Tourism on Urban Fabric Components

Literature mentioned European urban destinations have encountered difficulties in effectively redistributing services and facilities between residents and tourists, resulting in negative consequences for the economic, sociocultural, and environmental dimensions that directly impact the quality of life for residents [17]. This section aims to recognize and understand the physical adverse effects of urban tourism and their intricate relationship with the components of the urban fabric.
Biagi and Bertocchi hold the view that the impacts of tourism can have both positive and negative effects on the destination. However, the negative impacts tend to be concentrated in specific areas, while the positive impacts may influence the destination as a whole [18] [10]. As a result, a limited portion of the destination’s physical space, services, and facilities are significantly affected by the adverse effects of tourism. This spatial concentration of the negative impact of tourism calls for targeted interventions and management strategies to mitigate these harmful consequences and ensure the sustainable development of the destination.
The main adverse effects recognized through the literature are overcrowding, tourism monoculture, deterioration of heritage and public space, road mobility congestion, privatization of public space and incompatible zoning and land use (Table 2). Many in the field claim overcrowding as the most mentioned adverse effect of urban tourism [19]–[22]. Empirical research indicates the spring months are frequently the most difficult owing to the combined presence of visitors and inhabitants, because many citizens leave the city during the summer months, “freeing up” room for tourists [9].

Table 2. Literature review.

Effect	Authors
Overcrowding	Bouchon [3], Aall [19], Arayalopez [20], Delacalle-vaquero [23], Gemar [1], Vanderborg [22], Novy [24], Pasquinelli [21], Koens [19].
Tourism monoculture	Vanderborg [22], Novy [24], Antunes [4]
Deterioration of heritage and public spaces	Fedyk [25], Novy [24]
Road mobility congestion	Bertocchi [26], Zmyslony [27], Fedyk [25], Bouchon [3]
Privatization of public spaces	Novy [24], Zmyslony [27]
Incompatible zoning and land-use	Delacalle-vaquero [23], Novy [24], Zmyslony [27]

According to Vanderborg, the development of tourist monoculture is a potentially dangerous effect as it tends to provoke counter-movements among various groups due to the unequal distribution of economic benefits, which are concentrated in specific areas, causing imbalances and inequalities [22]. The massive proliferation of souvenir shops near points of interest, the concentration of short-term rentals in residential buildings, and the repeated presence of restaurants with similar characteristics (extended opening hours, English-language menus, and location near landmarks) are frequently symptoms of this effect, which conveys a perception of a sameness landscape to the users of the city.

Regarding the privatization of public space and the development of incompatible land use, the absence of urban regulations that consider the intensity of tourism in the destination, combined with the constant demand from the tourism sector, can result in businesses such as restaurants, bars, and cafes expanding their physical footprint by encroaching upon surrounding public spaces. Consequently, residential areas that were historically utilized by residents for leisure and everyday activities are now experiencing the effects of public space being privatized, ultimately leading to the displacement of the local population [24].

In addition, the excessive pressure of tourist flow on cultural heritage and public spaces leads to the continuous deterioration of these areas [25] [24]. This effect is closely linked to the strain placed on public transportation systems. When there is a concentration of tourists in specific areas, both tourists and residents seeking to go to other locations tend to use the same routes and modes of transportation. Consequently, there is an increase in traffic and congestion, which can hinder the mobility of residents and disrupt the daily functioning of the city. As a result, residents may experience inconveniences such as delays in public transportation and difficulties accessing local services and points of interest [3].

The nature of the urban fabric, as a tangible element of the destination, implies the inevitable presence of tourism infrastructure and services. In the city core, these elements become a focal point where the adverse effects of tourism can be perceived more intensely, establishing a correlation between these effects and the components of the urban fabric. In addition, the convergence of tourism practices with other forms of mobility, work and leisure has blurred the boundaries between tourists and residents, which has amplified the impact of tourism on the various components of the urban fabric (table 3).

As tourists have a restricted spatial and temporal budget compared to local users, they often rely on social media and tend to flock to tourist-oriented areas [5], leading to the potential emergence of adverse effects. This continuous growth of tourists in certain zones has significantly transformed the perception of residents toward tourism and has taken a toll on urban fabric components that compose the physiognomy of contemporary cities [9].

Overcrowding in tourism is strongly related to the strain exerted by the flow of tourists, which has a broader influence on the city. The large number of visitors can cause traffic congestion (1), crowding in public areas and hotspots (2) (5), and increased demand for services (3) (4), all of which can have a detrimental impact on inhabitants' comfort and well-being. Additionally, due to the saturation of areas of interest and the lack of authenticity in the urban environment, tourists may feel a deterioration in the quality of their tourist experience. According to studies, tourism congestion may lead to disputes between tourists and inhabitants, as well as a decrease in the destination's perceived livability [19], [24], [17][3], [10], [19].

The deterioration of heritage and public space mainly affects landmarks of interest, including emblematic buildings, squares, or parks (2) (5). These places hold great importance in the collective imagination of the local community and are often featured prominently in "place branding" campaigns, attracting a high volume of tourists. Unfortunately, this increased tourist flow can contribute to the physical deterioration of these landmarks, ultimately impacting their functionality and cultural value [25].

Table 3 Correlation between urban fabric elements and adverse effects.

Adverse Effects / **Components**	**1** Transportation Network	**2** Public Spaces	**3** Infrastructure	**4** Transportation System	**5** Landmarks	**6** Buildings
Overcrowding	◆	◆	◆	◆	◆	
Deterioration of heritage and public spaces		◆			◆	
Tourism monoculture		◆				◆
Privatization of public spaces	◆	◆				
Incompatible zoning and land-use						◆
Road mobility congestion	◆			◆		

The presence of tourist monocultures is linked to the existence of incompatible uses in the built environment, occurring in both residential and commercial buildings (2). In the case of informal commerce, this activity is commonly found in public spaces (6). Additionally, the privatization of public space primarily manifests in squares, streets, and sidewalks, corresponding to components (1) and (2). Finally, road mobility congestion mainly affects networks (1) and transportation systems (4), and it can even lead to system failures in cities already facing mobility challenges.

5. DISCUSSION

Considering the social dynamics of tourism and its relationship with the city's elements, it becomes crucial to zoom in on a smaller scale and prioritize the perspective of pedestrians. By focusing on the pedestrian's point of view, we can gain a comprehensive understanding of the interconnectedness between tourism and physical spaces [14]. Additionally, it is vital to acknowledge the significance of public spaces, transportation networks, and landmarks and the key elements that form part of these subsystems. This recognition allows us to clarify the intricate relationship between the city's physical form and its social, cultural, economic, and environmental dynamics. Moreover, it helps to comprehend how both residents and tourists interact, move, and engage in various activities within the urban landscape's enclaves [28].

However, it is crucial to acknowledge that both tourism and contemporary cities are undergoing rapid and dynamic transformations. Therefore, studies conducted a few years ago may no longer be applicable or relevant to address the current challenges they encounter. To achieve sustainable tourism growth and ensure the wellbeing of both residents and visitors, it becomes imperative to understand and manage the present-day dynamics of tourism in actual spaces [29].
Similarly, considering the multi-dynamic nature of the impact of tourism, assessing its effects from a social perspective presents a challenge due to variations in residents' interests and levels of tolerance [30]. However, recognizing the negative physical impacts on the urban landscape can serve as a preliminary step in identifying the origins of these social adversities [20]. Nevertheless, it is essential to acknowledge that the effects of urban tourism are not uniform and can differ based on the unique context and characteristics of each destination. Furthermore, comprehending these effects necessitates a multidimensional approach that encompasses economic, sociocultural, and environmental dimensions. Finally, the complex and interconnected nature of the adverse effects and the urban fabric is evident. These consequences often evoke conflicting sentiments, particularly in areas already experiencing conflicts and tensions related to space and the use of urban infrastructure [25] [4]. The influx of tourism can further exacerbate pre-existing issues, leading to multifaceted challenges that extend beyond overcrowding [31]. Hence, it is imperative to conduct an in-deep analysis of the adverse effects and undertake empirical studies on its various components, in order to adopt a transformative approach towards sustainable urban policies.

6. CONCLUSIONS

The recognition and assessment of urban fabric elements play a vital role in tourism development, as these subsystems influence tourists' experiences and impact locals' quality of life. The study presents insights into the interplay between the relationship of tourism and the urban fabric, showcasing the importance of integrating a holistic approach that seeks the involvement of stakeholders and the community as a priority. These aspects are essential for the development of practical tools to assess the scenario faced by cities.
In today's contemporaneous cities, this review can serve as a starting point for empirical assessment of the negative effects of urban tourism on the urban fabric and the development of sustainable guidelines strategies. The study emphasized the pivotal role of urban fabric elements in shaping the tourism experience in cities and, highlighted the importance of active planning and analysis of the built environment to identify potential negative effects of urban tourism. The findings support the existing relationship between the nature of urban tourism and the city as a whole and the importance from a scale-down perspective in the analysis of tourism impact.
While this research offers valuable insights, it also acknowledges its limitations that should be addressed in future studies. Due to the parameters of databases and search criteria, some literature related to the positive effects of tourism might have been excluded from this study. Although these positive effects are of interest, they may be covered in specific studies that are not directly aligned with the focus of the proposed research. However, it is important to consider the multidimensional nature of tourism and expand future research to encompass the economic, social, and environmental dimensions. Likewise, an in-depth analysis of urban fabric elements considering the complex dynamics of urban change and tourism evolution is needed.
Urban tourism is an ongoing and powerful force of change, deeply intertwined with everyday urban life. Without diligent management and strategic planning, cities are vulnerable to the risk of harmful transformations in their social and urban fabric, which can lead to a potential loss of authenticity and give rise to tensions between locals and tourists. Furthermore, it is crucial to recognize the pivotal role of urban planning and existing urban morphology in shaping tourism consumption patterns to achieve sustainable development over time.

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Green infrastructure adaptation and contribution to urban ecosystem services in the context of global warming

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0.ABSTRACT

Climatic change is responsible for the main environmental hazards that directly affect ecology and society. This reality is exacerbated in areas with high levels of human activity, resulting in biodiversity loss and the urban heat island effect that have been gradually increasing along urbanization processes. Scientific community and governmental institutions agree about greening cities as a strategy for mitigating global warming. However, there are controversies regarding which plant species are suitable for urban areas, given the changes in land use and resulting changes in air and soil chemistry from pollutants. It is essential to ensure the growing stability of plant species and their positive ecosystem services (ES) ranges for reducing pollution and mitigating the urban heat island effect. This study develops a state of the art about indicators regarding to ES and those affecting the environment where plant species try to survive on. Results suggest the importance of urban morphology and surface composition on plant adaptation; while both morphology and altered atmosphere run by urban activity, turn into different ES values.

1.INTRODUCTION

Global warming is predicted to become into a general temperature increase from 2.4-2.6 ºC in temperate climates to 3.2-4 ºC in dry regions along upcoming century [1], those generating a novel climatic scenario that turns into heat waves and dry stages increase up to 50% [2]. This new climatic context alters ecosystems and other human life-essentials such cultivars [3], and human health itself population, corroborated by the life spam decrease that was observed [4], also inversely correlated to biomass [5]. It has been observed that aforementioned biomass reduction generates the Urban Heat Island (UHI) due to surface moisture reduction and Evapotranspiration Index (EI) change[6], those exacerbating global warming effects[6]. EI change is being characterized in some study cases by a spatial gradient in urban context, from dense nucleus to surrounding rural areas [7], that can be extrapolated in to green cover surface and cooling potential [8]. Therefore scientific community and policy makers agree on urban greening actions to face UHI hazards in cities [9]. At international scale, UN proposed Global Goals for Sustainable Development promulgates necessary steps to ensure more sustainable cities, ecosystem preservation, climatic adaptation and gender equality; while European community gets behind natural restoration policies [10].
The implementation of green strategies in cities, on the other hand, presents multiple indicators to consider in order to build a comprehensive framework on Ecosystem Services (ES), a term that varies according to its scope of application. Collier defines ES as the benefits derived from a complex and uncontrollable natural system, which serve as a tool for urban planners or institutions to understand anthropocene ecosystems [11]. The new ecological framework of recent decades has increased the value of ES for their application in biodiversity conservation [12] or the reduction of environmental causes harmful to human health [13], leading to the development of a set of international indicators on ES in cities, generally classified by supporting, provisioning, or regulatory services [14–16]. These indicators can be summarized into three main areas: climate regulation and atmospheric greenhouse gases, contribution to and enhancement of biomass and biodiversity, and water cycle regulation and contribution to soil formation (Table 1) [14, 17–22].

Urban ES are an indicator of the contribution of biomass to the regulation of the inhabited environment, which is affected by urban heat islands and climate change. In this same scenario, there is a specific environment in which vegetation must survive, and it has been observed that native vegetation exhibits a lower damage index [23], as well as a higher adaptability to the new climatic reality by thermophilic species [24]. Within this framework of benefits, there is both an anthropocentric perspective in terms of the advantages gained, as well as an ecological perspective focused on adaptation.

Table 1. Summary of urban ES proposed by literature [14], [17]–[22]

Atmosphere	*-Air quality amelioration: CO_2 fixation and O_3, NO_X, SO_2, PM_{10}, $PM_{2,5}$, CO reduction* *-Climate regulation, facing extreme temperatures* *-Noise absortion*
Vegetation	*-Resources: Food, energy, industrial materials* *-Cultural Services: Social resources and wellbeing* *-Growth stability* *-Biodiversity richness* *-Pest and diseases reduction*
Soil	*-Nutrient provision, Biological richness* *-Water regulation: inflation and storage, reducing run-off and erosion*

2. OBJECTIVES AND METHODOLOGY

This study analyzes the most influential indicators, to understand possible contradictions or inertia, according to mentioned two principal frameworks of green infrastructure related to adaptation and contribution to ES

Following the three areas of action for ES shown in Table 1, a state of the art has been developed using both review articles and empirical studies on geographic analysis. For each area, the search for indicators has been organized into two parts, focusing on the two frameworks of study being compared. On one hand, the adaptation of vegetation types to each environment (ecological medium for dispersion and reproduction, atmospheric medium, and soil); and on the other hand, indicators related to the contribution to different ecosystem services.

After gathering the indicators, they have been grouped according to the framework of study (adaptation or contribution), area (ecological, atmosphere, or soil), and type of indicator (urban and construction-related, or vegetation properties).

Table 2. Classification frameworks of studied indicators.

Study framework	*-Adaptability* *-contribution to ES*
Scope	*-Urban ecology: Introduction, reproduction, dispersion, competiveness and extinction* *-Soil* *-Atmosphere*
Indicator type	*-Urban and construction indicators* *-Vegetation traits* *-Climatic parameters*

3. RESUTS

3.1. Urban ecology: Introduction, reproduction, dispersion, competiveness and extinction

The starting point for species colonizing cities is related to people's preferences for horticultural activities or landscaping purposes, leading to the incorporation of exogenous species [25]. Subsequently, the potential of different species to reproduce and colonize is influenced in cities by pollution and fragmentation of green infrastructure [25, 26].

The development of fragmented green patches makes certain dispersal or reproduction systems challenging, thus reducing zoophilic strategies for these purposes [27], except for entomophilous reproduction carried out by ants, which leads to the presence of specific species adapted to this strategy [28]. This decrease in Reproduction and Dispersal (R/D) driven by animals is not only affected by fragmentation itself but also by the exceptional conditions prevalent in urban environments. For instance, different bee communities are negatively affected by direct radiation but benefit from temperature or population density [29].

On the other hand, densely built and fragmented environments have facilitated the colonization of species with aerial reproduction and dispersal (R/D) strategies, which are influenced by wind patterns [26, 27]. Cities with urban heat islands and specific morphological characteristics, such as orientation and proximity to green spaces or bodies of water, result in temperature fluctuations within the urban fabric and, in turn, changes in wind speed within the urban canyon [30].

The urban environment's suitability towards the mentioned R/D strategies, along with specific environmental conditions, can lead to the displacement of certain species over others. One key factor is the lifespan of different species, where introduced species tend to have a wider range [26] and eventually dominate the urban greenery. This is due to the predisposition of the population towards woody species (trees and shrubs), which, after being introduced into private plots, disperse throughout the rest of the city [25, 26] . In terms of species longevity, their size serves as an indicator of adaptation to the urban environment. Following Raunkiaer's classification (1934), phanerophytes (trees) and chamaephytes (shrubs) exhibit a lower risk of extinction [28, 31]. Conversely, geophytes and hemicryptophytes, both of smaller stature, have a higher risk of extinction [31].

3.3.1. Adaptation to built up soils

The physical and chemical properties of soils are essential for the establishment of different vegetation types. These properties are altered in urban contexts by various elements, and the correlation between the presence of certain vegetation types and the soil environment provides insights into their affinity. On one hand, the use of construction materials, notably concrete and other cement-made materials, contributes to soil calcification and shows a correlation with the number of calcicolous species [28]. The composition of these materials leads to a generalized soil alkalization, as evidenced by the number of species adapted to alkaline conditions [28].

On the other hand, access to certain nutrients for plants is limited in the urban environment, while others may increase due to changes in biological activity, which shapes a specific structure and biochemistry where vegetation and other organisms interact [32]. One of the studied phenomena is mycorrhizal associations, crucial for nutrient uptake by plant roots and their protection against pathogens and drastic environmental changes [33]. These associations exhibit specificity based on different environmental conditions (temperature, CO2 concentration) and soil composition, such as pH or nitrogen availability [34, 35]. They serve as secondary indicators of the vegetation's affinity for a specific fungal community, which, in turn, can indicate the concentration of pollutants, particularly heavy metals [33, 36]. Conversely, the high nitrogen concentration in urban soils, and consequently, the presence of nitrophilous species [28], is a more direct indicator.

Additionally, water stress caused by imperviousness and subsequent runoff shows differential responses among vegetation types. Several studies have compared vegetation types based on physiological properties or the climatic region of origin.

In terms of physiological properties, following Raunkiær's system (1934) based on plant life forms, Williams et al. (2015) concludes that therophytes and geophytes, both herbaceous plants, exhibit greater resilience during drought periods, with a slight mention of geophytes facing competition from taller species in urban spaces [26]. The different levels of resilience in these species are related to the point of leaf turgor loss [38], which, in turn, is linked to the aridity index of the soil of origin, as demonstrated in a study by Zhu et al. [39]. Apart from aboveground characteristics, the root composition in the soil among species, especially at depths of 60 to 120 cm, correlates with total transpirable soil water (TTSW), which plays a crucial role during drought periods [40].

3.2.2. Contribution to water cycle

The regulation of water flow mediated by green infrastructure encompasses four essential processes: Interception (I), Transpiration (T), Infiltration (IF), and Runoff Reduction (RE) [41]. Following this framework, Rahman et al. (2023) studied the influence of different geometric parameters of vegetation architecture, starting with the contribution of spatial arrangement, which plays a crucial role in water flow, particularly in I and T, both positively related to canopy openness. On the other hand, IF and RE are increased with a closed arrangement, although to a lesser extent. Additionally, biomass levels and species composition are determining factors for RE and erosion [42]. According to Rahman et al., T levels are most affected by these indicators, with a stronger correlation observed in tropical and riparian species [41]. The continuity of the green infrastructure, as an indicator of better soil quality, contributes to infiltration, physical stability, bulk density, as well as organic-mineral content and pH. However, in highly urbanized areas, continuity is compromised due to fragmentation and alternating arrangement of individual planting pockets [43].

Furthermore, fragmentation, as discussed in the previous subchapter, leads to a reduction in biological activity, which is crucial for maintaining soil structure and porosity, favouring both IF and RE [41]. Root architecture and distribution also play a role, where shallow roots and surface vegetation (herbaceous) contribute to RE, while IF and T are correlated with deeper root networks [41, 44]. The composition, dimensions, and capillary structure of roots are additional factors influencing these relationships [45]. The composition of the mineral substrate further influences these dynamics, with greater differences observed in sandy soils [41]. All these factors ultimately affect the amount of water infiltrated or transpired by vegetation, and the total value of transpirable soil water varies depending on the species, with root functional traits playing a determining role [40].

Regarding individual properties, size and age are positively correlated with I levels and, to a lesser extent, with IF and RE, while inversely related to T levels [41]. Leaf Area Index (LAI) is proportional to all four parameters, with a particular impact on I and T. Canopy profile specifically influences I and RE by increasing vertical density, while canopy height inversely affects RE [41]. Branch inclination enhances interception while reducing infiltration. Finally, leaf composition, size, type, surface characteristics, and hydrophilicity are primarily proportional to interception levels [41].

3.3. Urban atmosphere

3.3.1 Resilience to urban heat island

The increase in temperatures due to urban heat islands leads to a change in atmospheric composition [46], impacting vegetation metabolism in carbon fixation and photosynthesis processes [47]. Various parameters discussed in the following subsection (3.3.2) contribute to more or less efficient water management and carbon fixation, influencing the resilience to rising temperatures. Different species exhibit variations in adaptability, as demonstrated in a study by Liu et al. (2021) where subtropical species showed higher adaptability [38]. Likewise, deciduous species tend to thrive in cities as they require more light and temperature [28].

Regarding physical properties characterized by height and leaf surface area, they are indicators strongly correlated with individuals adapted to urban contexts [26]. Esperon-Rodriguez et al. (2020) studied the recurring properties that characterize vegetation with greater flexibility during drought periods in warm and dry climates, resulting in a higher presence of species with lower specific leaf area and denser wood [48]. This finding aligns with Wolf et al. (2020), which suggests increased resistance of woody species to urban heat islands [27]. Another aspect related to vegetation's physiological properties is leaf colour, where species with high anthocyanin content and red pigmentation demonstrate better response and adaptation to drought events [49].

3.3.2. Contribution to reducing urban heat island and green house gasses

The contribution of vegetation to the reduction of heat and greenhouse gases is mediated by its photosynthetic activity, where solar energy absorption allows for the capture and fixation of atmospheric carbon for biological activity. In contrast, when in contact with inert materials, solar energy is accumulated as thermal energy, contributing to surface warming.

Therefore, at the street scale, the mitigation of the urban heat island can be measured based on surface temperature, considering factors such as tree species, tree height, leaf density, base height, and leaf area index [50]. The choice of pavement materials also plays a significant role, with higher thermal peaks observed with asphalt [51, 52]. Radiant temperature also varies with the height-to-width ratio of the urban canyon [51]. On the other hand, climate and urban morphology are influential indicators for cooling at a height of 1.1 meters [50].
During photosynthetic activity, most plants increase water vapour transpiration in the leaf area, which helps regulate temperature at this level. Thus, transpiration-induced cooling is correlated with tree height and leaf area density [50]. Finally, thermal comfort in terms of PET (Physiological Equivalent Temperature) shows a stronger relationship with climate, species, and street orientation [50, 51].
However, photosynthesis does not always occur in the same way. Temperature levels play a crucial role and are negatively related to CO_2 concentration, accelerating carbon fixation and reducing atmospheric levels [46]. Conversely, with increasing temperature, growth is reduced, and ozone (O_3) concentration increases due to nitrogen compounds (NO_x) and volatile organic compounds (VOC) [19].
These various environmental conditions result in different water and carbon flows that vary according to species, stomatal composition, tree canopy geometry, canopy continuity, cuticular morphology, hydrophobicity, leaf hairiness, which are critical indicators in reducing primary and secondary pollutants [49, 51-53]. There is also a positive relationship between leaf dissection index (FDI), trichome density, leaf area index (LAI), and suspended particle deposition, while leaf specific area and leaf wetness show a negative correlation with atmospheric PM reduction [53].

4. CONCLUSION

Regarding the adaptation of vegetation in urban environments, on one hand, atmospheric indicators are limited to temperature, wind, and radiation. On the other hand, greenhouse gases or suspended particles would have a direct effect on the presence of certain types of vegetation, except for the influence of heavy metals on the presence of fungal species in their mycorrhizal relationships with plants.
On the other hand, the effects of the city on adaptability, dispersal, and reproduction are related to morphological aspects that can be reflected in the fragmentation of biomass continuity, resulting in ecological barriers and exacerbating imbalanced levels of wind speed, solar radiation, and temperature. All of these factors affect the composition of a specific environment, determining which species will show greater capacity for reproduction and dispersal in the urban environment.
However, changes in soil structure are decisive and related to the presence of construction materials, which alter the soil chemistry and provide a niche for species that love eutrophic environments with high nutrient input, especially nitrogen (N). Regarding water flow, the physical composition of the soil and root architecture are the main related indicators, while the concentration of certain compounds due to pollution, such as N, would not have an apparent influence.
In terms of climate regulation and the hydrological cycle in the soil, in addition to the aforementioned indicators, the concentration levels of greenhouse gases in the atmosphere are crucial. They affect photosynthesis, carbon fixation, nutrient acquisition in the soil, and internal water regulation of plants. These factors result in specific levels of ecosystem services (ES), such as reduced runoff, infiltrated water, or transpiration by biomass.
Comparing the indicators in the three studied environments, a distinct importance of urban indicators can be observed, which impact the adaptability of vegetation and its contribution to urban ecosystem services. The permanent effects of urban spaces, reflected in their morphology and construction, influence both the way vegetation adapts to the environment and the provision of ES. Conversely, temporary changes in the city, caused by socio-economic activity, primarily the composition of the air due to pollution, will only condition ES.

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Identification of in-between spaces by patterns of use. A case study in San Sebastian

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0.ABSTRACT

Currently our cities do not meet citizens' needs for a full daily life, especially in terms of proximity spaces for socialization and care works. The COVID 19 health crisis has made this problem much more evident. For this reason, we assert that it is necessary to recover and create a network of in-between spaces between public and private spheres through urban regeneration actions, creating more cohesive communities.

Historically, these spaces have proven to be important social catalysts and the most appropriate setting for collective care works. Therefore, we seek to identify the physical and social characteristics that characterize these spaces, so that we can detect existing ones and regenerate potential in-between spaces in urban fabrics around us.

The communication analyzes the use patterns of potential in-between spaces located in the neighborhood of Benta Berri in Donostia. This analysis of use patterns will be carried out through several indicators. These are identified through the conclusions derived from a previous bibliographic analysis and are parameterized in this work where they are applied to the case study of Benta Berri, concluding the degree of in-between character of the urban spaces of this neighborhood.

This work is part of a broader research whose objective is to identify the physical characteristics related to the adequate/inadequate functioning as in-between space of urban spaces, so that the degree of in-between character of the spaces of our neighborhoods can be improved; or even the physical and functional characteristics of these spaces can be replicated in the regeneration of urban fabrics where these spaces do not exist.

1. INTRODUCTION

The cities in which we live do not respond correctly to the needs of citizens, especially in terms of spaces for socialization and community care works. Although proposals of a more humanistic nature that seek to comprehensively address the needs of the citizenry –understanding that this is diverse– are currently gaining strength, they do not succeed in defining the scenario; giving rise to simple, rigid and excessively defined spaces that suffocate urban life [1] or that are not sufficiently suggestive to give rise to the achievement of an adequate urban life.

Local scale public spaces, and more specifically those that we call "in-between spaces", are the elements that cohere community life in our close environment [2]–[4]. Moreover, in recent years various authors [2]–[7] have claimed the importance of in-between spaces –although not all use the same nomenclature– as generators of activity and relationships in the community. Likewise, the COVID crisis has shown the importance that these proximity spaces have in people's daily lives and they are now essential in the regeneration of obsolete urban fabrics.

The researches on in-between spaces study some of their characteristics [2, p. 23], [4, pp. 186–187], [5, pp. 562–563], [7, p. 426], [8, p. 96], [9, p. 59]. But, although they identify key characteristics of these spaces, there is no research that proposes a method for identifying these spaces.

Therefore, in this paper we seek to propose a set of indicators to identify in-between spaces in real urban fabrics through the use of indicators.
This methodology is part of the author's PhD thesis and is preceded by a previous phase of study of the physical and functional characteristics of the in-between spaces. First of all, we carried out a literature review in order to define the key characteristics of in-between spaces to be able to propose the indicators. Subsequently, we mapped activities through structured non-participant observation in four case studies and used the indicators to determine the in-betweenness of these spaces. With the results obtained we will work on the identification of the common physical characteristics in the spaces that have obtained the best results in the indicators, so that we can replicate these characteristics in the regeneration of in-between spaces.
In this communication we discuss the conceptual definition of the indicators and their application to the mapping of activities that we have carried out in the case study of Benta Berri, a neighbourhood of Donostia-San Sebastian.

2. WHAT MAKES A SPACE AN IN-BETWEEN SPACE?

In order to identify in-between spaces of an existing fabric, we first need to understand what they are as well as their functional characteristics. So that we can use those characteristics to propose the indicators.
According to Carricas [7, p. 17] "It can be said that the in-between space is the spatial area between the two extremes of the purely public and private, between open and closed, between collective and individual. The term between is important, because without its condition of bridge - spatial and social - it loses the condition of in-between". This definition tells us about the role of "gradient of publicity and privacy" that in-between spaces play [3, p. 75], mediating between public and private space. All authors who deal explicitly with the in-between space agree that its defining characteristic is its bridging condition [7, p. 17], [9, p. 59]. Understanding that bridge as a gradient or hierarchy of spaces that links the public and private spheres [2, pp. 68–69], [4, p. 165], [5, pp. 562–563], [10, p. 37] and allows us to attenuate the leap from our home to the city.
In addition to their bridging character, in-between spaces have certain characteristics that can be key in identifying them. Below, we show the three characteristics that are most commonly mentioned in the literature on in-between spaces and that we have used as a basis for setting out the indicators, since they are related to the way in which in-between spaces are used.

SOCIAL CHARACTER

It is precisely thanks to this gradient of privacy that these spaces are an important setting for social relations. Since, the reduction in the number users, due to the increasingly private character, increases the possibility of encounters and relationships between the same neighbors [4, pp. 53, 185], [10, p. 41], [11, p. 25], which despite seeming superficial become deeper because of their regularity [2, p. 23], [12, p. 197]. This implies that many users know each other and form a community that is reinforced by the social relationships that occur in those same spaces [2, p. 67], [5, p. 565], [7, p. 35], [9, p. 59]. Based on this characteristic, we have proposed two indicators. One that measures the familiarity of the users and another that measures the size of the groups.

CARE WORKS

Thanks to these recurrent social relationships that are maintained with other users and the proximity of these spaces to the housing environment (especially in private and some community in-between spaces), these spaces are often the scenario of care works [2, p. 67], [4, p. 185] and have been so historically [4, p. 68], [6, pp. 30–31]. This familiarity contributes to their perception as safe spaces in which vulnerable groups such as the elderly and children can carry out leisure activities [5, p. 564], [7, p. 426], with less surveillance and sharing care works [4, pp. 186–187], [13, p. 20].

The public figures mentioned by Jane Jacobs [8, p. 96] often play an important role in this collectivization of care works that occurs in in-between spaces and help reducing the level of supervision while maintaining the perception of safety. From this feature we have also extracted two indicators. The first measures the presence of care work and the second measures the level of collective supervision over children.

PERCEPTION OF SAFETY AND PRESENCE OF VULNERABLE GROUPS

The perception of safety is one of the most common and important characteristics in in-between spaces. The reason for this perception is familiarity with other users [7, p. 36] and knowledge of the physical and social environment [14, p. 3], which allow us to form an idea that the space is safe.
A resulting characteristic of the perception of safety is the presence of people of different age groups – especially older people and children– [4, p. 170], [5, pp. 564–565], [7, p. 426] and of different sexes [15, p. 18], [16, p. 21]. The diversity of age groups is often largely due to the fact that we feel comfortable and safe in these spaces, and with the idea that vulnerable people in our care spend time in them. On the other hand, according to some authors [4, pp. 186–187], [15] women tend to use spaces they consider safe to a greater extent and therefore finding a higher percentage of women among the users of a space denotes perception of safety. Based on this characteristic we have proposed an indicator that measures the presence of women and vulnerable groups.

Table 1 Identification of spaces studied in Benta Berri.

SPACE TYPOLOGY			CODE
PERIMETER BLOCK COURTYARD			PM00
PEDESTRIAN STREET			CP00
PLAZA/SQUARE			PL00
PARK			PR00
PROMENADE			PS00
INCIDENTAL SPACE AND OTHERS			IN00
BENTA BERRI	1	PM01	Placita Resines y Oloriz
	2	PM02	Placita de Sagastizar
	3	PM03	Placita de Txapaldegi
	4	PM04	Placita Errota-Aundieta
	5	PM05	Placita del Padre Meagher
	6	PM06	Placita del Padre Vinuesa
	7	PM07	Placita de Eguzkitza
	8	PM08	Placita de la Escuela Politécnica
	9	CP01	Calle Oihenart
	10	CP02	Plaza José María Sert (calle parte sur)
	11	CP03	Calle Simona de Lajust
	12	PL01	Plaza acceso desde calle Benta
	13	PL02	BerriPlaza José María Sert
	14	PL03	Plaza Julio Caro Baroja

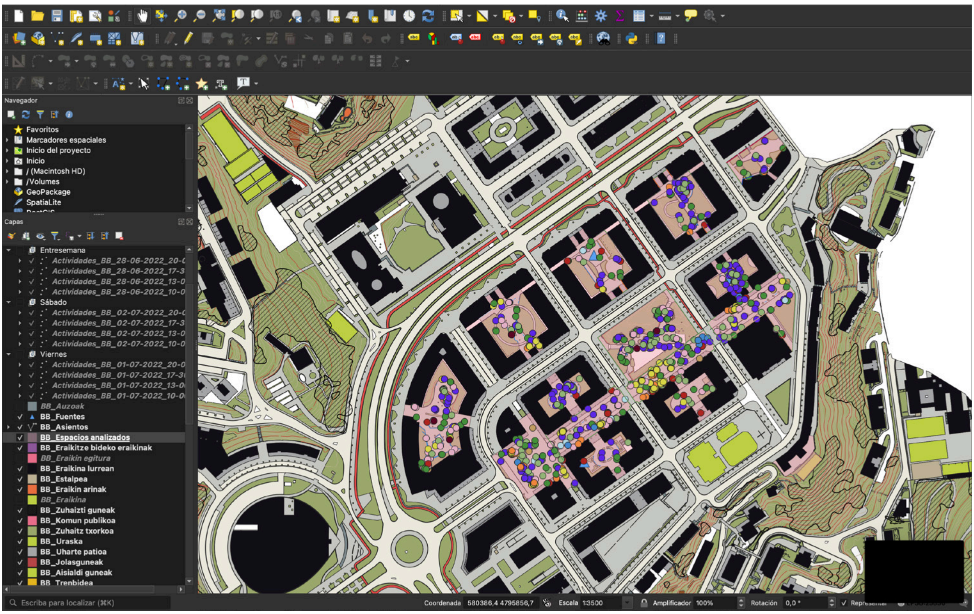
To categorize the activities, we based on the methodologies of Gehl Institute [18, pp. 28–29] and Project for Public Space [16], focusing on the stationary activities. We have added the category of "Casual encounters" and "Care works" to the categories raised by Gehl Institute, as they are activities of great importance in in-between spaces and are key to raise the indicators. These groups of activities (Table 2) are divided into specific activities that we have not analyzed in this paper.

Table 2 Categories of activities recorded

ACTIVITY GROUP NAME	CROUP CODE
CASUAL ENCOUNTER	EC
CARE WORKS	CD
CONVERSATE	CV
PASSIVE LEISURE	OP
ACTIVE LEISURE	OA
COMMERCIAL	CM
CONSUME	CO
CIVIC	CI
SUBSTANCE USE	CS
HOMELESS	SH
WAIT	ES
CULTURE AND SHOWS	CU
TOURISM	TU

We have performed activity mapping on three different days (Tuesday, Friday and Saturday) and at four different times of the day (10:00, 13:00, 17:30 and 20:00), to see if the patterns of use of the spaces change during the day and the week. Therefore, we made 12 activity mapping sessions in each space. Below, we show an image of the mapping of the case study, in which each point shows us an activity (Fig.1).

Figure 1 Image of the mapping of activities in Benta Berri.



Next, we show a summary table (Table 3) of the activities registered in each space by activity category. In this case, we show the activity CD05 "Pet walking" in a differentiated way since, as we explain in the next section, we do not count it as a care activity for the purpose of calculating the indicator.

Table 3 Summary of the activities recorded in each space

	Total activities	CV total	EC total	OP total	OA total	CM total	CO total	CD total	CD05 total	CI total	CS total	SH total	ES total	CU total	TU total
CP01	70	8	3	13	3	6	19	9	3	0	2	0	4	0	0
		11,43%	4,29%	18,57%	4,29%	8,57%	27,14%	12,86%	4,29%	0,00%	2,86%	0,00%	5,71%	0,00%	0,00%
CP02	121	5	6	22	6	11	56	5	5	1	4	0	0	0	0
		4,13%	4,96%	18,18%	4,96%	9,09%	46,28%	4,13%	4,13%	0,83%	3,31%	0,00%	0,00%	0,00%	0,00%
CP03	74	8	1	13	7	4	13	14	7	2	3	0	2	0	0
		10,81%	1,35%	17,57%	9,46%	5,41%	17,57%	18,92%	9,46%	2,70%	4,05%	0,00%	2,70%	0,00%	0,00%
PL01	21	0	0	8	2	2	0	1	4	1	2	0	1	0	0
		0,00%	0,00%	38,10%	9,52%	9,52%	0,00%	4,76%	19,05%	4,76%	9,52%	0,00%	4,76%	0,00%	0,00%
PL02	123	17	2	39	19	0	2	22	13	0	2	7	0	0	0
		13,82%	1,63%	31,71%	15,45%	0,00%	1,63%	17,89%	10,57%	0,00%	1,63%	5,69%	0,00%	0,00%	0,00%
PL03	143	11	1	26	17	13	37	24	3	3	2	0	1	5	0
		7,69%	0,70%	18,18%	11,89%	9,09%	25,87%	16,78%	2,10%	2,10%	1,40%	0,00%	0,70%	3,50%	0,00%
PM01	67	1	0	6	18	3	0	32	5	0	1	0	0	1	0
		1,49%	0,00%	8,96%	26,87%	4,48%	0,00%	47,76%	7,46%	0,00%	1,49%	0,00%	0,00%	1,49%	0,00%
PM02	26	3	0	10	1	0	1	2	3	0	5	0	1	0	0
		11,54%	0,00%	38,46%	3,85%	0,00%	3,85%	7,69%	11,54%	0,00%	19,23%	0,00%	3,85%	0,00%	0,00%
PM03	42	3	0	8	3	2	14	3	5	0	1	3	0	0	0
		7,14%	0,00%	19,05%	7,14%	4,76%	33,33%	7,14%	11,90%	0,00%	2,38%	7,14%	0,00%	0,00%	0,00%
PM04	65	1	1	5	23	0	0	32	0	0	1	0	0	2	0
		1,54%	1,54%	7,69%	35,38%	0,00%	0,00%	49,23%	0,00%	0,00%	1,54%	0,00%	0,00%	3,08%	0,00%
PM05	34	2	0	1	11	0	0	16	3	0	1	0	0	0	0
		5,88%	0,00%	2,94%	32,35%	0,00%	0,00%	47,06%	8,82%	0,00%	2,94%	0,00%	0,00%	0,00%	0,00%
PM06	16	1	0	3	6	0	1	1	1	0	3	0	0	0	0
		6,25%	0,00%	18,75%	37,50%	0,00%	6,25%	6,25%	6,25%	0,00%	18,75%	0,00%	0,00%	0,00%	0,00%
PM07	9	0	0	3	1	0	0	0	4	0	1	0	0	0	0
		0,00%	0,00%	33,33%	11,11%	0,00%	0,00%	0,00%	44,44%	0,00%	11,11%	0,00%	0,00%	0,00%	0,00%
PM08	81	17	0	21	13	0	8	13	3	1	3	2	0	0	0
		20,99%	0,00%	25,93%	16,05%	0,00%	9,88%	16,05%	3,70%	1,23%	3,70%	2,47%	0,00%	0,00%	0,00%

INDICATORS FOR IDENTIFYING IN-BETWEEN SPACES

Once the activities have been recorded, we used the functional characteristics mentioned above, which are common in in-between spaces, to propose indicators to detect the in-between character of the spaces studied.

The indicators focus especially on the ties created in the community [2, p. 67], [5, p. 565], [7, p. 35], [9, p. 59] and on functional characteristics that denote perception of safety, such as the presence of care jobs [2, p. 67], [4, p. 185], and the presence of vulnerable collectives [5, p. 564], [7, p. 426]. The proposed indicators are the following:

-Familiarity among users (social character).
-Group size (social character)
-Care work (care works)
-Age and gender diversity (diversity of people)
-Level of collective supervision (care works)

For each indicator we have calculated the result of the formula applied in all the spaces of each case study. As we will see when explaining the indicators, each one has different ranges of values and in some cases even different units. Therefore, with the intention of being able to compare these data, we have weighted the results by assigning a value from 0 to 10 to the result of each space, with 0 being the worst result and 10 the best. We obtained the intermediate values by linear interpolation. In this way, compliance with all the indicators is measured on the same scale and we can know the in-between character of each of the spaces analyzed by adding the value obtained in the different indicators.

As we have mentioned, the five indicators cover three different areas that show the existence of in-between character: the existence of ties among users (familiarity among users and size of groups), the presence and form of care works (care works and level of collective supervision) and the presence of vulnerable or more selective groups in the use of spaces. Therefore, to avoid a space specialized in only one of the three areas scoring too high, we have proposed that all three groups have the same weight. This, in turn, means that in order to calculate the weight of each indicator in the final result, we have averaged the indicators of each group, so that the maximum score would be 30 points.

We explain below the reason for using each indicator and how we have calculated it.

FAMILIARITY AMONG USERS

As we have mentioned, one of the most important characteristics of in-between spaces is that most of their users know each other [2, p. 67], [7, p. 35], [9, p. 59]. Therefore, we have proposed an indicator that seeks to reflect the familiarity between users of the spaces based on two sub-indicators: one that measures the number of casual encounters and another that measures the number of tourists (unknown users).

According to Ervin Goffmann [12] casual encounters are the basis for creating stronger long-term relationships and, in turn, these relationships generate ties with our community [19, p. 284]. Therefore, we consider that the percentage of casual encounters between users of the space is an indicator of great interest to define the in-between character of the analyzed spaces. To calculate this sub-indicator (FEC) we calculated the percentage of casual encounters with respect to total activities.

With the second sub-indicator (FTU) we seek to show the presence of tourists in a space reflect that there are people who are totally unknown to the usual users of the space. In addition, the activities of large groups of tourists show us that the place is of a very public character [18, p. 30], and therefore not in-between. On the other hand, we felt it was important to include this sub-indicator, as it helps us to get a truer picture of the in-between character by correcting for the high number of casual encounters that can occur in very central areas with a large number of people. The way to calculate this sub-indicator (FTU) is the same used for the casual encounter sub-indicator, but the best value is the absence of tourist activities.

Once we obtained both sub-indicators, we calculated the mean. Thus, the spaces that have a high value for casual encounters and a strong tourist presence reflect that there is less familiarity among users.

Finally, we would like to point out that this indicator does not always reflect the existing sense of community, especially in spaces where we have not recorded casual encounters. This is because the fleeting nature of casual encounters makes it difficult to record them, and this can lead us to have the mistaken image that there is no sense of community or casual encounters (although both exist). Therefore, we have included the group size indicator to detect the level of sociability and familiarity among users. We could increase the reliability of this indicator by increasing the length of stay or the number of stays in each space in the activity mapping.

GROUP SIZE

According to Whyte [15, p. 17] in small-scale squares and living spaces there is a higher proportion of couples and small groups.

This indicator gives us an image of the level of socialization that exists in the space, and can indicate sense of community. Since there are activities carried out by a group of people –such as caring for children and the elderly (CD01 and CD02), walking pets (CD05), etc.– that are not planned and could be understood as a long casual encounter, or even an expected encounter. In addition, this indicator helps us to obtain an image of this possible sense of community in the case of spaces in which we have not recorded casual encounters (EC01).
For this indicator, we calculated the percentage of groups of different sizes that carried out the activities. We did not take into account the activity "Formal sitting/standing for a drink" (CO01), as we did not separate people sitting on terraces into groups due to the difficulty of differentiating the groups and the limited interest of this type of activity for this study. We have defined the groups based on the Gehl Institute [18, p. 30] space mapping methodology. These are the proposed groups:

-1 person
-2 people
-3-7 people
-8+ people

To decide the weight that each group has in the calculation of the indicator, we based on the AHP method (Analytic Hierarchy Process), developed by Saaty [20], which allows us to calculate a total assessment for a situation in which different variables of equal or different weights are involved. In this method we must establish the importance of each variable in relation to each of the other variables, in order to calculate the weight it should have in the final result. This comparison is made with a pairwise comparison matrix (Table 4), in which we establish the difference in importance that a variable has with respect to each of the other variables.
We have applied this method to establish the weight (eigenvector) that the value of each group has in the total result. We have given greater weight to pairs and small groups, since these are the group sizes that indicate the most in-between character. Regarding the activities carried out by large groups, although they are not a clear indicator of in-between character, they indicate greater knowledge of other users of the space, so we have given them greater weight with respect to the activities carried out by single persons.

Table 4 Pairwise comparison matrix of group sizes

People	1	2	3-7	8+	Eigenvector
1	1	1/5	1/5	1/2	0,0769
2	5	1	1	1/3	0,3846
3-7	5	1	1	5/2	0,3846
8+	2	2/5	2/5	1	0,1538
				CR	0,00%

Once the weight of each type of group has been calculated, we can calculate the total value of the indicator by multiplying the coefficients obtained (eigenvectors) with the percentage that each type of group occupies with respect to the total number of activities.
Once the weight of each type of group has been calculated, we can calculate the total value of the indicator by multiplying the coefficients obtained (eigenvectors) with the percentage that each type of group occupies with respect to the total number of activities.

For this indicator we have calculated the percentage of caregiving activities with respect to total activities, but we have eliminated the activity "CD05 Pet walking"; since people are not usually so selective about the level of safety of a space when choosing to walk their pet and we believe that the selection is usually based more on the proximity of the space to the home and the presence of green areas.

PRESENCE OF VULNERABLE GROUPS AND WOMEN

The perception of safety instilled by in-between spaces encourages the presence of people from vulnerable age groups –especially the elderly and children– [4, p. 170], [5, pp. 564–565], [7, p. 426] and women [15, p. 18], [16, p. 21]. The diversity of age groups is often largely due to the fact that the perception of safety instilled by these spaces makes us comfortable with the idea of vulnerable people in our care spending time in them. As for the presence of women, according to some authors [4, pp. 186–187], [15] women tend to be more selective with the spaces they use and therefore finding a higher percentage of women among the users of a space denotes perception of safety.
To calculate this indicator, we have followed a more complex process than in the previous cases. First, we have divided the indicator into three sub-indicators:

-Presence of girls aged 0-4 years and 5-14 years (DNI).
-Presence of people over 65 years of age (DPM)
-Presence of women (DMU).

To calculate the first sub-indicator, we have calculated the percentage of children in relation to the total number of users of each space. From this result we subtracted the percentage occupied by this population group in the neighborhood, since we are interested in seeing whether the age groups are over- or under-represented. Thus, a positive result represents the abundance of children in that space and denotes security, while a negative result implies a deficit in the representation of the age group.
For the second sub-indicator the process is the same as that used in the first, but counting users in the elderly age group (65+ years). In the case of the third sub-indicator, we have calculated the percentage of female users in each space.
Once the three sub-indicators were obtained, we obtained the value of the indicator for each space by averaging the three sub-indicators. In this case, we have used the average, since we found no evidence in the literature to suggest that any of the sub-indicators deserved to have a greater weight in the result.

LEVEL OF COLLECTIVE SUPERVISION

The high level of perceived safety leads caregivers to allow vulnerable people such as children to spend time in in-between spaces with less supervision than in less known spaces [13, p. 20] or cared for in a communal way, sharing care works collectively [4, p. 191]. This is largely because they know other users of the space and rely on them for indirect or diffuse care of their dependents. The public figures mentioned by Jane Jacobs [8, p. 96] often play an important role in this collectivization of care works that occurs in in-between spaces and help in the reduction of the level of supervision, maintaining the perception of safety. Therefore, we believe that the level of collective supervision is an indicator of great interest to identify the in-between character.
This indicator is the most complex of those we have used, as it is made up of 2 or 3 sub-indicators, depending on each space. In turn, we measure these sub-indicators at three different distances, so we obtain between 6 and 9 different results. These sub-indicators give us a picture of the level of direct and indirect supervision of children in each space.

To do this, we have started by identifying the activities carried out exclusively by children. From these activities we have excluded those that only include dependent children (0-4 years), since their young age demands a higher level of supervision by the caregivers and could distort the image of the general level of supervision that exists in that space for children of different age. In addition, we have decided to divide the age group “Children” (5-14 years) into “Children 2” (5-9 years) and “Preadolescent” (10-14 years) for the calculation of this indicator, as the level of independence of children changes a lot in those age groups. In this way we have obtained a clearer and more faithful picture of the level of supervision in each space analyzed.

Once we separated the activities performed by the two age groups, we performed three buffers of the activity points at 3m, 10m and 20m. According to Gehl [2, p. 75] the 3m distance is the limit distance at which we usually engage in conversations and allows us to fully perceive the feelings of the other person. The 20m distance represents the limit at which we are able to perceive the other person’s feelings and recognize him or her easily. The 10m distance represents a midpoint supervision between conversation and recognition.

Then, in each space we have selected three different groups of activities that gather potential supervisors/ caregivers of the activities in which only children participate. The groups are as follows:

-Childcare activities that do not include other children (CD01 without children).
-Childcare activities that include children and casual encounters (CD01+ EC01)
-Consumption activities in bars (CO01 + CO02 + CO03).

In the first group we have only included caregiving activities without other children, because we understand that this represents that the caregivers are taking care of the nearby group of children in a fairly direct way. We have called the level of supervision measured with this group direct supervision (NSD), as it represents the number of caregiver groups that are paying attention to each children activity. The second group includes caregiving activities with other children and casual encounters. We have included casual encounters here, since in some cases they mask caregiving activities due to the hierarchy of recorded activities that we have established. Caregiving activities with other children represent two possible scenarios:

-Caregivers are caring for other children while keeping an eye on those doing activities on their own.
-Persons who are caring for other children and are not responsible for ones doing activities independently, but are caring indirectly.

We have called the type of supervision measured by this group (NSM) mixed supervision, as it includes people who are performing caregiving activities, but have other children or activities that reduce the level of attention they give to the caregiving activity.

The third group represents caregivers who are consuming outside the bars, terraces and surroundings. This group that measures the level of indirect supervision (NSI) will only be applicable in cases where there is a bar or restaurant in the space analysed or very close by, since otherwise we would obtain results that do not reflect reality. We have included this third group because in the fieldwork we have found that consumption activities on terraces hide indirect care on several occasions.

Once we have made the different buffers and identified the three groups of supervisory activities, we have calculated the number of supervisory activities found within the buffers generated by each children’s activity. Then, in each analysed space we added up all the supervisory activities counted within the buffers (ASUP) and divided it by the total number of activities in which exclusively children participated (ATOT). In this way, we obtained the supervision coefficient (KS) for each type of supervision (direct, mixed and indirect), which represents the number of adult groups for each group of unaccompanied children. A low result represents a high level of collective supervision, while a high result indicates that there is not too much collective supervision and, therefore, a perception of safety.

$$K_S=K_{SD}+K_{SM}+K_{SI}$$

$$K_{SD}/K_{SM}/K_{SI}=A_{SUP}/A_{TOT}$$

But the KS coefficient is not sufficient to indicate the level of supervision, since the level of independence of children is very different depending on the age group. Therefore, we have included the age coefficient (KE), which defines the percentage occupied by girls in the "Preadolescent" age group (10-14 years) in the total number of activities in which only girls participate (ATOT). This allows us to discern whether the low levels of supervision are due to the perception of safety or to the age of the children.
Finally, we have included the total amount of activities performed by girls (ATOT) in the equation, since the abundance of these activities shows us perception of safety and indicates that children regularly perform activities in that space. The scarcity of such activities may indicate that the level of supervision calculated does not reflect reality.
We took as a basis the total number of children activities (ATOT) for the equation, since this is what shows us the recurrence with which the children frequent the space with a certain degree of independence. We then weighted this value with the two coefficients we calculated.

$$N_S=A_{TOT}*(1/(1+K_S))*(1/(1+K_E))$$

Once the formula was defined, we calculated the value of the supervision coefficient (KS) for each distance of each sub-indicator (Table 5), since each buffer has within its different supervision activities. Thus, we have divided the coefficients according to the distance at which they are measured and they have the following nomenclature:

Table 5 Denomination of the sub-coefficients

SUB-INDICATOR		DISTANCE		
		3M	10M	20M
DIRECT SUP.	(K_{SD})	K_{SD1}	K_{SD2}	K_{SD3}
MIXED SUP.	(K_{SM})	K_{SM1}	K_{SM2}	K_{SM3}
INDIRECT SUP.	(K_{SI})	K_{SI1}	K_{SI2}	K_{SI3}

Once we calculated the value of each sub-coefficient, we must decide the weight that each one has in the calculation of the supervision coefficient used in each sub-indicator (KSD/KSM/KSI). To do so, we have relied on the AHP method, as in other indicators. We have applied this method to establish the weight (eigenvector) that each sub-coefficient has (Table 6). We have given a higher value to the sub-coefficients calculated at greater distances, since a high value in these sub-coefficients reflects a less tight and more collective supervision than a high value in the closest sub-coefficient (3m). In other words, the farther away we detect supervision activity, we consider that there is more collective supervision.

Table 6 Pairwise comparison matrix of the weight given according to distance.

	3M	10M	20M	EIGENVECTOR
3M	1	1/3	1/5	0,1047
10M	3	1	1/3	0,2583
20M	5	3	1	0,6370
			CR	3,34%

At the time of setting up the equation for each coefficient we have taken into account that each buffer contains the count of the buffers of smaller radius, so we only have to add the difference that exists in the value of the sub-coefficient.

$$K_{SD}=K_{SD1}*0,1047+(K_{SD2}-K_{SD1})*0,2583+(K_{SD3}-K_{SD2})*0,6370$$
$$K_{SM}=K_{SM1}*0,1047+(K_{SM2}-K_{SM1})*0,2583+(K_{SM3}-K_{SM2})*0,6370$$
$$K_{SI}=K_{SI1}*0,1047+(K_{SI2}-K_{SI1})*0,2583+(K_{SI3}-K_{SI2})*0,6370$$

With these formulas we calculated the coefficient of direct, mixed and indirect supervision for each space. Next, we used another pairwise comparison matrix (Table 7) to establish the weight of each type of supervision on the total value of the collective supervision indicator. In this case, we will have two different matrices, depending on whether or not there are bars and restaurants in the space studied.

Table 7 Pairwise comparison matrix of the different types of supervision

	N_{SD}	N_{SM}	N_{SI}	EIGENVECTOR
N_{SD}	1	1/3	1/3	0,1429
N_{SM}	3	1	1	0,4286
N_{SI}	3	1	1	0,4286
			CR	0,00%

	N_{SD}	N_{SM}	EIGENVECTOR
N_{SD}	1	1/3	0,2500
N_{SM}	3	1	0,7500
		CR	0,00%

Thus, the calculation of the final indicator will be the result of one of the following two formulas.

$$N_S=A_{TOT}*(1/(1+(K_{SD}*0,1429+K_{SM}*0,4286+K_{SI}*0,4286)))*(1/(1+K_E))$$

$$N_S=A_{TOT}*(1/(1+(K_{SD}*0,25+K_{SM}*0,75))*1/(1+K_E))$$

4. RESULTS

Below we show the tables with the results of the different sub-indicators (Table 8), the graphs representing the values of these sub-indicators (Fig.2 and Fig.3) and the table showing the values of each indicator and the final result of each space (Table 9).

Table 8 Sub-indicator values

BENTA BERRI										
SPACE	FEC	FTU	TG	CD	NSD	NSM	NSI	DMU	DNI	DPM
PM01	0,00	10,00	7,90	9,70	6,99	7,13	9,15	5,71	9,27	1,55
PM02	0,00	10,00	5,40	1,56	0,00	0,00	0,00	5,35	0,00	3,44
PM03	0,00	10,00	3,25	1,45	2,11	2,13	1,90	3,22	2,39	1,84
PM04	3,10	10,00	9,50	10,00	4,38	8,10	10,00	5,80	8,42	1,48
PM05	0,00	10,00	10,00	9,56	4,73	4,01	5,85	4,79	8,58	1,74
PM06	0,00	10,00	8,91	1,27	3,69	3,75	2,53	10,00	10,00	0,00
PM07	0,00	10,00	0,00	0,00	0,67	0,65	0,60	0,00	1,74	3,35
PM08	0,00	10,00	8,97	3,26	3,05	3,41	3,67	1,20	2,25	1,22
CP01	8,65	10,00	6,54	2,61	1,20	1,39	1,28	4,60	1,58	6,35
CP02	10,00	10,00	6,96	0,84	1,98	2,41	1,14	5,70	0,66	2,39
CP03	2,72	10,00	7,76	3,84	5,13	5,13	4,72	5,42	2,68	4,88
PL01	0,00	10,00	2,51	0,97	0,33	0,33	0,30	2,86	2,32	3,35
PL02	3,29	10,00	8,24	3,63	6,28	6,37	6,55	4,59	4,96	10,00
PL03	1,41	10,00	8,90	3,41	10,00	10,00	7,90	6,26	2,23	3,38

Figure 3 Superposition of the graphs for the different spaces

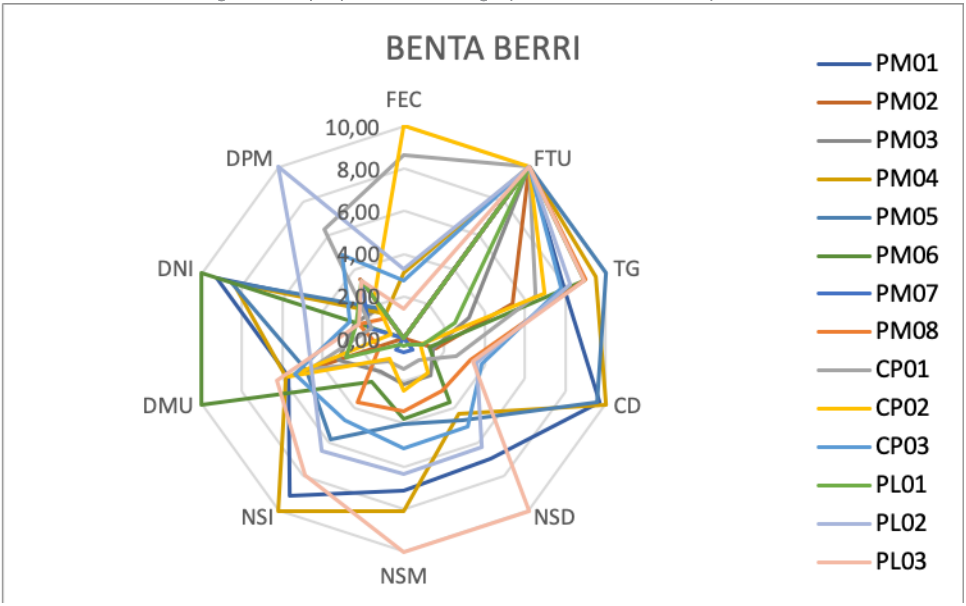
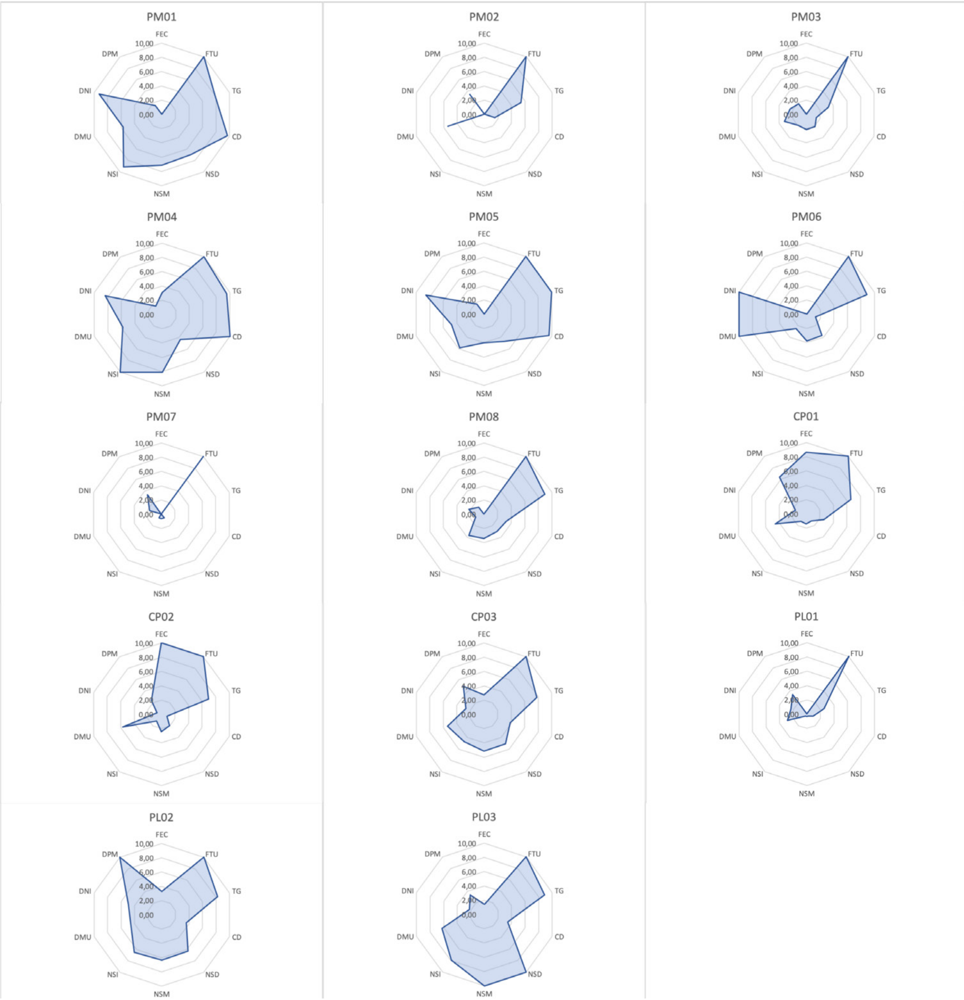


Figure 2 Graphs of the sub-indicators for each space



When reading the graphs, we should note that the sub-indicators are grouped according to the characteristic to which they belong (Fig.4), so the direction in which the graph is tilted tells us which characteristic is the most outstanding among the three in the case of that space. In the example of PM01, we can see that it is a fairly balanced space, since it has good results in 7-8 sub-indicators. But, there are other spaces, such as CP02, that have very good results in one characteristic, but not in the rest, so they do not show so much in-between character.

The latter is of great importance, since standing out very much in only one of the characteristics may indicate that the space is too public. For example, a very high value in sociability (especially in casual encounters and group size) may indicate that it is a very public meeting space. The same may be true of spaces that have a very high value on the care works sub-indicator, which may be public spaces that are very child-oriented, but lack the community of an in-between space.

Figure 4 Interpretation of graphs

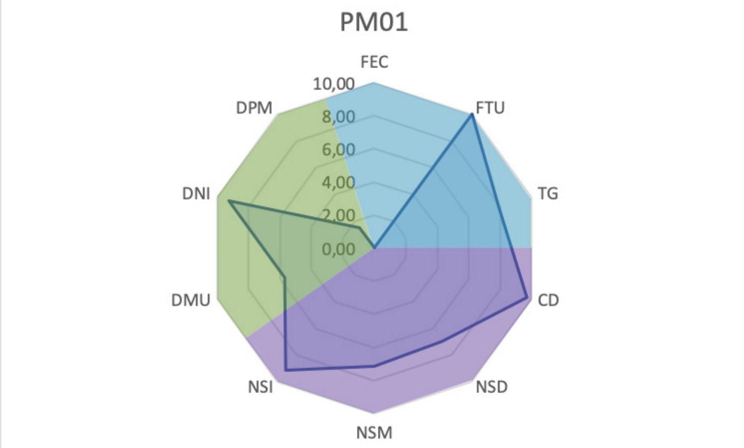


Table 9 Results of the indicators for each area

BENTA BERRI						
SPACE	CASUAL ENCOUNTER	GROUP SIZE	CARE WORKS	COLECTIVE SUPERVISIÓN	USER DIVERSITY	TOTAL
PM01	0,00	7,90	9,70	7,54	7,74	20,30
PM02	0,00	5,40	1,56	0,00	2,69	6,17
PM03	0,00	3,25	1,45	2,24	1,82	5,29
PM04	3,10	9,50	10,00	7,63	7,19	22,31
PM05	0,00	10,00	9,56	4,45	6,81	18,81
PM06	0,00	8,91	1,27	3,97	10,00	17,07
PM07	0,00	0,00	0,00	0,70	0,28	0,62
PM08	0,00	8,97	3,26	3,53	0,00	7,88
CP01	8,65	6,54	2,61	1,45	5,12	14,75
CP02	10,00	6,96	0,84	1,97	2,66	12,54
CP03	2,72	7,76	3,84	5,46	5,42	15,31
PL01	0,00	2,51	0,97	0,35	2,52	4,43
PL02	3,29	8,24	3,63	7,11	9,70	20,84
PL03	1,41	8,90	3,41	10,00	4,70	16,56

Regarding the results of the analyzed spaces, the best results are those of spaces PM04, PL02 and PM01, respectively. At first it may seem that there are other spaces with better scores in the sub-indicators, especially in the case of PL02. But we must keep in mind that each sub-indicator and indicator does not have the same weight in the calculation of the final score. Since the three characteristics have the same weight in the result, but they have different number of indicators and sub-indicators.
If we study spaces PM04 and PM01, we can see that they are spaces clearly oriented to children's leisure.

But we believe that this does not imply a bias in the indicators, since in these spaces the caregivers end up creating relationships with other people due to the recurrence of care works (scores of 10.00 and 9.70), to the point of carrying out care activities in a communal way (very high values in group size) and with a good level of collective supervision (7.63 and 7.54). This shows us that the users consider these spaces to be safe and that there is a community of people they trust and with whom they can share care work.

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The PL02 plaza, on the other hand, has more modest values. But it is worth noting that it is a very balanced space because it scores well on all three characteristics measured by the indicators. In addition, it is a space in which there is a great diversity of users and the community is well represented (diversity of users 9.70) and, therefore, it instils a great perception of security. Although it does not have a very high rating for the care works indicator –due to the fact that it is a space with a greater variety of activities than PM04 and PM01 – it has a good level of collective supervision, so we understand that it is a space that caregivers consider safe, in which young children can carry out activities with greater independence.

In general terms, we see that spaces oriented to children's leisure score well overall (PM01, PM04 and PM05). This makes sense, since the care work activities that occur in these spaces tend to help forge relationships that deepen over time. So, in the long run, these activities are done in a communal way and this increases the group size of the activities that occur in such a space and, consequently, the score on the indicators.

5. CONCLUSIONS

Regarding the accuracy of the indicator scores, we are aware that these indicators are relative, since we establish the values by comparing the spaces with other spaces in the neighborhood. This entails the risk of a space scoring very well because it is located in a neighborhood where the rest of the spaces have very little in-between character. Therefore, it is necessary to include more spaces to increase the reliability and accuracy of the assessment. This will also help us to see differences between the in-between character of spaces in different locations and urban fabrics. As mentioned, there are 3 other case studies where we are calculating the indicators, so we will go from 14 spaces to 49.

Although including more spaces increases the accuracy and reliability of the assessment, comparing each space with the spaces in its own neighborhood also gives us valuable information; since a space may have in-between character because the spaces in its surroundings have worse characteristics and the users choose among the existing options in the neighborhood. Moreover, in many cases the in-between spaces complement each other and function as a network (Gehl, 2006 p.68-69; Col-lectiú Punt 6, 2019 p.165), so it is necessary to understand each space studied within its context. Therefore, we think that for future cases it will be interesting to make the measurement of the indicators on a neighborhood scale and comparing all the spaces as a whole, to see if a space has good results because it is in a bad environment or because it really has an intermediate character.

These indicators represent a first proposal based on the literature to identify in-between spaces in existing fabrics and the results of the indicators seem to be quite in agreement with the perceptions we had when mapping the spaces. This is especially confirmed in the case of the worst performing spaces (PM07 and PL01). Although we consider that in general the results are quite faithful to reality, we see the need to establish some mechanism to define the reliability of the indicators/sub-indicators in each space based on the number of activities.

Since there may be areas, such as PM06, that have very good results, but very few activities (16 activities compared to the average of almost 64). This lack of activities may indicate that these results are the result of a small data set that does not represent the usual operation of that space.

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Interactive energy mapping for effective plans and policies. A user-centered UBEM approach

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0.ABSTRACT

The European Commission published a Renovation Wave Strategy in October 2020 aimed at improving the energy performance of the building stock and to contribute to achieving the ultimate goal of climate neutrality. One of the key principles of this strategy is to make a better use of available funding, thus targeting inefficient buildings and vulnerable areas. The building renovation programmes are channelled through local authorities, which have to identify the eligible areas of the city where building renovation can be incentivized to maximise the returns on the investment. However, cities do not currently have objective instruments to support energy based decisions. Despite the growing interest in urban energy performance in the last decade, few Urban Buildings Energy Models (UBEMs) are actually available to evaluate the energy implications of plans and policies Most of the existing models have one or several of the following limitations: (a) They require time-consuming geometric modelling (b) They rely on building-scale thermodynamic models and hence their applicability is limited to a few blocks (c) They are only based on statistical correlations and do not account for the specific characteristics of buildings and urban fabric and (d) They are targeted to design and planning teams and need to be operated by expert consultants. This paper will describe a novel UBEM approach to adapt and combine thermodynamic and daylighting models with original morphological analytic algorithms to map the energy demand in districts and cities, portraying estimates of current or alternative planning scenarios. The tool will support policy-makers to target the most effective energy policies based on the characteristics of the building stock and urban form in each part of the city. The range of applications of this tool is not limited to local renovation plans but they can also support decision making at multiple levels (from buildings to regions). This ongoing research has developed an urban building energy model that takes account of urban morphology, construction specifications and user behaviour thus enabling meaningful analysis of the likely impacts of energy plans and policies at city and regional scale as well as the assessment of individual buildings. It has defined a sound, flexible and scalable energy model structure that incorporates the key variables that influence building energy use for heating, cooling and lighting, exploiting current datasets and facilitating a gradual integration of innovative methods and updated data.). The next stages of the research will focus on the model’s integration into an online digital platform, to display dynamic and interactive urban energy maps. These maps will show estimates of the current demand of the building stock as well as the potential savings from building renovation interventions. They are aimed at a general audience as well as to inform local plans and policies.

1. INTRODUCTION

The COP21 Paris Agreement recognizes the important role of cities and calls for a rapid reduction of greenhouse gas emissions through adaptation to climate change. The EU commits to implement the 2030 Agenda for Sustainable Development, including Sustainable Development Goal 11 (“Make cities inclusive, safe, resilient and sustainable”).

To achieve the necessary energy transition in cities, it is essential to increase the integration of energy systems and raise energy efficiency significantly beyond current regulatory levels, creating energy-positive communities. Moreover, the climate emergency and the progressive process of population concentration in urban areas, either in the consolidated centers or in their periphery, are two strongly related phenomena that characterize the current global context. The figures that illustrate the environmental impact of cities associate up to 75% of carbon emissions and 80% of energy consumption to urban activities [1]. For this reason, the search for solutions to mitigate the negative effects of urban activities has been a priority included in the main research programs and development objectives (Objective 11 of the SDGs, Mission: climate-neutral and intelligent cities of the Research Framework Program of the European Union Horizon Europe).
The construction sector accounts for more than a third of energy use and a similar proportion of energy-related greenhouse gas (GHG) emissions and consequently plays a central role in the transition to climate neutrality. Although, according to International Energy Agency (IEA) estimates, the energy efficiency of new buildings led to a reduction in energy intensity (measured as energy use per m²) of 0.5-1% per year since 2010 However, its effect was outweighed by the higher growth of the stock built, causing a global increase of 40% in GHG emissions associated with the building sector during the same period [2]. In addition, there are still too many new buildings being built that do not meet the established energy efficiency consumption targets. Some recent studies on Energy Efficiency Certificates (EPC) showed that almost 50% of buildings built in 2018 only reached level C or below [3]. Also, the rehabilitation of the existing park is too slow; Recent reports show that the percentage of buildings classified as EPC level E in 2019 is the same as in 2014 [4], they have not been improved. These figures indicate that, overall, progress in energy efficiency in our cities is insufficient. Although there is great potential to reduce consumption, both in new and existing buildings, it has not been able to materialize until now. Therefore, it is essential to address the problems that prevent these additional savings from being realized in order to decarbonize our built environment and thus achieve climate neutrality on the European agenda.
One of the main factors preventing further progress has to do with the existence of the discrepancy between actual energy consumption and that forecast in buildings ("performance gap"). Numerous studies have confirmed that there is a systemic underestimation of the energy used in heating, cooling or lighting buildings (for example, [5], [6]). The disparity is attributed to a combination of factors, including the high degree of uncertainty when entering important parameters of energy calculation models [7]. This is because regulations and standards based on the most common modeling approaches currently have inherent limitations, which include assumptions about thermal comfort, use and operation of mechanical heating and cooling, etc.
In recent decades there have been great advances in the tools available for carrying out urban analysis. Geographic information systems, Big Data, the use of sensors and smart meters, or information captured from satellites have made it possible to reveal and quantify some of the undesired consequences of urbanization processes and the impacts on urban ecosystems. Until now, however, these tools have been more effective in making diagnoses than in designing solutions. The current moment of urban research is characterized by this dilemma. There is a great capacity for data processing and information generation, but also great uncertainty about the application of these capacities in urban planning and management.
One of the fields, within urban science, that can benefit from these new techniques is energy analysis. The energetic evaluation of the urban form has been widely explored since the decade of the seventies of the last century. However, although the modeling of thermodynamic processes at the building scale could be developed with great precision for decades [8], the systematic investigation of energy aspects at the urban scale has been limited by the complexity of the factors involved and the difficulty in handling large databases [9]. Today's technology offers new possibilities to go beyond the assessment of individual buildings and take into account the symbiotic interaction between urban buildings and their surroundings more precisely, analyzing urban morphology and its influence on energy demand from one perspective.

Between the years 2000-2010 several projects were carried out, in what we could call a first generation of Urban Building Energy Models (UBEM) such as CitySim [10], SunTool [11], Urban LT [9], ClimateLite [12], or Ursos [13]. In the following decade (2010-2020), the research focused on interoperability, which facilitates the use of the calculation power of well-established thermodynamic models at the building scale, such as the Urban Modeling Interface, UMI [14] or the most recent City Energy Analyst , CEA [15]. These two projects are mainly focused on new developments and are optimized for an intermediate scale (few urban blocks or a small district). Therefore, there is still a need for tools that allow energy analysis to be carried out on a large scale, which are accurate and usable in the planning and management of cities.

2. PRECEDENTS

The majority of UBEMs that have been developed in recent years focus on energy supply planning: generation, smart grids, or grid management. Reviews of scientific literature on this topic classify the models based on the concept they adopt to [a] adapt to the urban scale and [b] energy calculation methodology [16]–[18] Table 1 summarizes the analysis of the different energy modelling approaches. In relation to the urban scale, the UBEM can be categorized, in a general way, based on their approximation:

-Top-down. In this approach, an aggregation level is used such that each unit of analysis encompasses multiple buildings. The level of resolution can vary from one or several blocks to the entire district or city.

-Bottom-up. These models start from the individual building, in a disaggregated way, either to make more detailed estimates on a smaller scale or to add them sequentially and generate large-scale predictions.

In relation to the energy calculation methodology, they are classified as follows:

-Thermodynamic models, sometimes referred to as “white -box” models. They apply building physics to calculate the energy consumption. A common approach is to classify the urban fabric into archetypes, which represent the common characteristics of use, typology, size and materials. In this way, only the archetype buildings are simulated and the results are extrapolated to the rest of the fabric that is represented by each archetype. Another option used by some models is to extract real samples of the urban fabric, simulate their demand and extrapolate the results. In this case the accuracy of the model depends on the density of the number of samples, which is proportional to the time and effort required to collect and process the necessary data.

-Statistical models, also referred to as “black -box” or “data- driven”. These models use available information and databases, of diverse origin and character, such as censuses, energy meters, sensors, etc. Statistical methods are used with these data to establish relationships between energy variables and other parameters that can characterize the urban fabric (for example, spatial, socioeconomic data...).

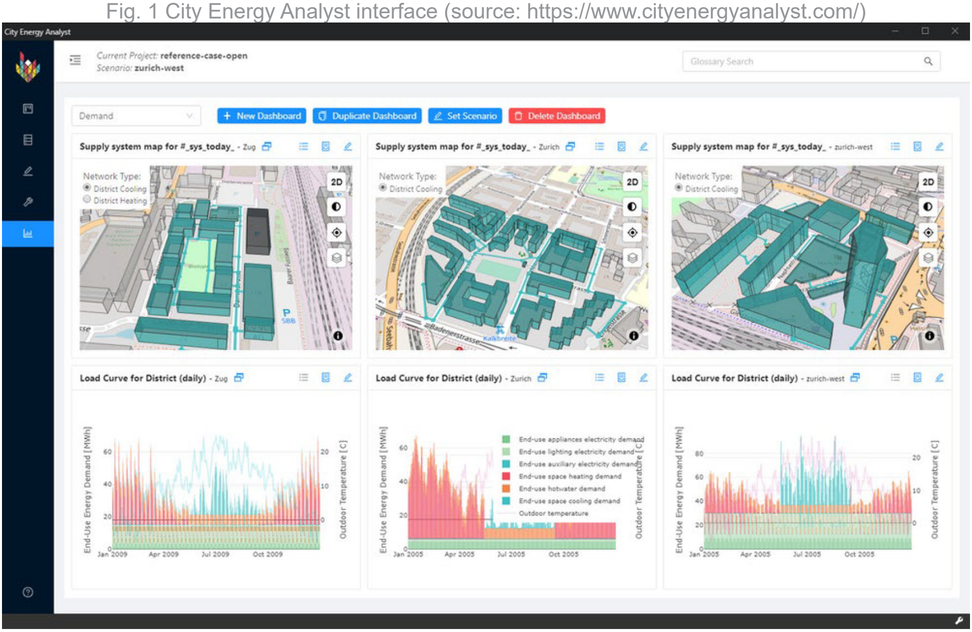
-Hybrid models. As their name suggests, they combine physical formulas with statistical methods. The goal is to reduce the number of parameters needed to make quick estimates.

The modelling approach is strongly dependent on the intended application. The spatial component has a great importance in urban design and planning, while network management can assume a higher degree of abstraction. We analysed a representative sample of the UBEMs that were developed in the last two decades which are considered closest to urbanism, they incorporate planning parameters and allow visualizing the relationship between form and energy through mapping:

-EEP, Energy and Environmental Prediction Model, [19]. One of the first energy models to incorporate GIS. It consists of an audit tool to quantify the city’s energy demand and emissions. Information is collected for each building from geographic databases. With these data, energy consumption and CO_2 emissions are estimated using a stationary energy model applied to residential buildings.

Urban LT [9] Urban LT uses Digital Terrain Models (DTMs) to obtain the perimeter and height of the buildings. By means of a specific image processing algorithm, the morphological parameters are derived from the MDT, feeding the LT model to carry out the calculations for lighting and thermal loads.
SUNTool [11] It was developed as an integrated model of resource flow (energy, water and waste) from buildings in new urban developments. It is based on dynamic thermal simulations, unlike LT and EEP which were based on stationary models.
Ursos [13] The energy model is integrated into a platform that assesses the sustainability of new developments, which considers, in addition to energy demand, environmental impact and quality of life. The energy model makes estimates of the demand for cooling, heating, domestic hot water applying a simplified methodology for calculating the energy balance.
Climate Lite [12] It was an experimental application to evaluate urban projects in the initial stages of the design phase. It provides calculations on the heating, cooling and lighting demand of buildings, which are based on the LT model, although the data acquisition process is manual, through a CAD-like interface.
Urban Modeling Interface-UMI [14] It is an application that uses EnergyPlus for the evaluation of urban environments. The scale of application ranges from a few blocks to a district. Its initial development was carried out in a CAD-3D environment (Rhino) for the introduction of detailed geometry.
CitySim [20] It is a refined version of SUNtool , introducing a simplified model of its own. Each thermal space is defined by three types of nodes (floors, walls, ceilings) each with a homogeneous temperature. Each node in contact with another space or the exterior generates a flow and a balance of energy. The model analyzes and adds those balances to obtain the final result. The model is integrated into a CAD-type application to generate the geometry, although it is possible to use XML files and integrate them into Rhino-Grasshopper .
City Energy Analyst -CEA [15] This is an application that integrates a district-scale energy model based on the ISO13790 demand simulation methodology and is developed as an extension of GIS environments. New capabilities have been added to the initial algorithm, such as the potential for integrating renewable energy, and a user interface (Fig. 1).

Fig. 1 City Energy Analyst interface (source: https://www.cityenergyanalyst.com/)



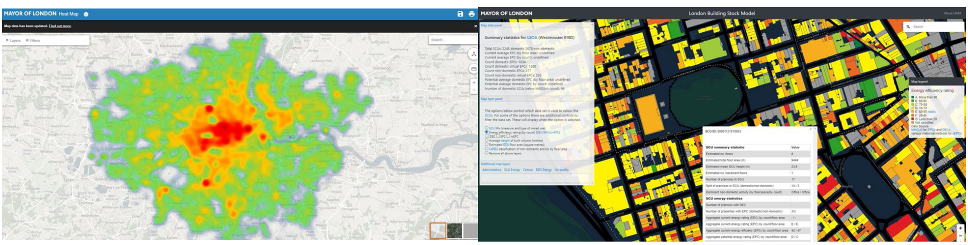
UBEM.IO [21] The latest trend in applications related to architecture and urbanism tries to develop tools that can be accessed through the browser, without need for desktop installation. UBEM.IO tries to apply a web-based methodology and to facilitate the realization of energy estimates for buildings on an urban scale. The workflow starts from georeferenced cartography (GIS), which contains information on heights and perimeters of buildings. This cartography is uploaded to an online platform that formats and organizes the information to generate archetypal buildings and extrapolate them to the urban fabric. The energy simulation is carried out, by default, in UMI. The energy simulation is not done online but through desktop applications.

The tools described above are examples of UBEM oriented and used in urban planning and design. They have been conceived to be incorporated into design processes, to evaluate the variation of energy demand in relation to urban typologies or land uses. The spatial component is highly relevant, so its definition and manipulation are a central part of the workflow of these methodologies. For this, two strategies are followed: the use of cartographic information systems (GIS) or manual modeling in CAD-3D environments. The former has the advantage of automation, allowing large-scale analysis. On the other hand, the main weaknesses are the risk of error due to the use of large databases, which entails filters and revision, and the gaps in critical data (such as materials, windows, etc...). Manual models allow for a greater degree of control and precision, but limits the ability to analyze large areas, which is time and cost consuming. Another important barrier to the implementation of these models has been the discontinuity of the tools, which almost always depend on public funding for their development. Of the examples above, only UMI, CitySim , and CEA are currently available, while UBEM.IO is under development.

As mentioned in the UBEM.IO case, the trend towards the development of applications directly accessible from the cloud has acquired great relevance in recent years, especially in the field of spatial representation. New libraries (eg . Webgl , Leaflet , Three.js…) facilitate visualization and interactivity directly from the browser. This opens up new possibilities for the creation of dynamic maps and models, beyond the conventional programs and applications mentioned above. There is still no known example of a portal that offers complete interactivity, which allows real-time energy demand to be calculated in real time. However, there are dynamic viewers that allow viewing consumption data, based on real data or model estimates. The most promising cases have been developed in the cities of London and New York:

One of the projects for mapping energy demand on an urban scale was the London Heat Map [22], supported by the Greater London Authority (GLA) and produced by the Center for Sustainable Energy (CSE) in 2009. In a geo-portal where It shows in detail the heating demand of buildings, the location of the generation plants in the city and the district heating networks. The initial objective was to identify opportunities for cogeneration and decentralization of power generation. The portal was updated in 2019, adding new capabilities, such as the possibility of selecting and calculating the consumption of specific areas, and incorporating building energy certificate databases.

Fig. 2 London Heat Map (left, source: https://maps.london.gov.uk/heatmap) and London Building Stock Model (right, source: https://maps.london.gov.uk/lbsm-map/public.html).



The London Building Stock Model (LBSM) [23] incorporates energy consumption data based on energy certificates into its interactive geoportal of public (DEC) and private (EPC) buildings. In those buildings where there is no certificate, a statistical model is used.

In New York a map of water and energy consumption of buildings [24] has been developed by the University of New York and the office of sustainability of the City Council. The portal exploits a 2009 ordinance whereby all public buildings of more than 1,000 m² and private buildings with a constructed area of more than 2,500 m² must report their energy and water consumption every year, this data is publicly accessible. The interactive map allows viewing and consulting this information for each building, both in 2 and 3 dimensions.

Other cities (Barcelona, Vienna, Boston, Amsterdam ...) have started projects to map the energy demand of the city's buildings. However, in most cases they have become obsolete, lack consistent data or have not had continuity.

Fig. 3 NYC Energy & Water Performance Map'. (Source: https://energy.cusp.nyu.edu)

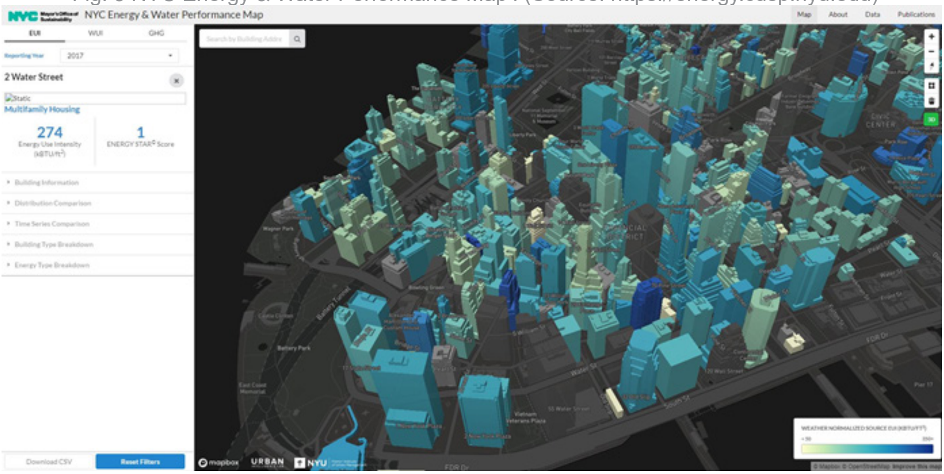


Table 1 Summary of urban energy models approaches

	Thermodynamic Termodinámicos	Statistical Estadísticos	Hybrid Híbridos
Weaknesses Debilidades	Requires detailed data Does not incorporate socioeconomic trends Intense computational demand Need for calibration Requiere datos detallados No incorpora tendencias socioeconómicas Intensa demanda computacional Necesidad de calibración	Depends on historical data Economically unfeasible if no data is available Difficulty adapting to design modifications Little capacity to assess the impact of rehabilitation or new technologies Depende de datos históricos Económicamente inviable si no hay datos disponibles Dificultad de adaptación a modificaciones de diseño Poca capacidad para evaluar el impacto de rehabilitación o nuevas tecnologías	Simplifies the study area using mean values Each model is specific for each application and field of study Need for calibration Simplifica la zona de estudio utilizando valores medios Cada modelo es específico para cada aplicación y ámbito de estudio Necesidad de calibración

Strengths Fortalezas	Demand simulation with different time scales (hourly, annual) Modeling of renewable energies and new technologies Determines the final use of energy and the impact of different technologies Permite introducir modelización de energías renovables y nuevas tecnologías Determina el uso final de la energía y el impacto de diferentes tecnologías	Includes socioeconomic effects It incorporates real consumption data (meters, invoices...) Incluye efectos socioeconómicos Incorpora datos de consumo real (contadores, facturas…)	Requires fewer input parameters Greater flexibility for optimization Optimization of computational capacity Requiere menos parámetros de entrada Mayor flexibilidad para optimización Optimización de la capacidad computacional

3. LITHEUM MODEL

In this research we develop a UBEM that builds off these previous experiences to provide an interactive urban energy portal that displays demand distribution patterns while allows for the evaluation of alternative retrofit scenarios.
LITHEUM is a Lighting and THErmal Urban Model that adapts a pseudo-dynamic energy model to the urban scale by integrating original algorithms that take into account the urban form, the properties of the building stock and the local climate. The model deploys an analytical grid to adapt the resolution to the scale, thus generating rapid simulations for large urban areas. Then, the model exploits cadastral information to infer the key building properties. Finally, the energy calculation is undertaken using building archetypes for each cell of the grid. This procedure is explained in detail in the following paragraphs.

3.1 Urban Morphology

The influence of urban morphology on the energy behavior of buildings is determined by spatial factors, such as solar obstruction or the shape of buildings. The Litheum model translates the urban morphology into a regular grid that contains a homogeneous building matrix defined by the average key geometric values contained within each cell. The resultant analytical mesh contains all the relevant information to conduct meaningful energy calculation, such as: the angle of solar obstruction, envelope exposure, orientation or the average distance between buildings. The transformation of the irregular and heterogeneous urban fabric into an analogous and regular structure greatly simplifies the energy demand calculations. This strategy takes a top-down approach. It starts by averaging the geometric attributes and performing the energy calculation for a building that represents the geometric mean values of each cell. The transformation is carried out through a series of algorithms that have been adapted from a previous research [25]. The spatial data is automatically calculated for each cell of the grid through these algorithms, which transform urban data (built-up area, land coverage), into relevant information for energy calculations (orientation, obstruction, exposure...). Each cell of the analytical mesh contains a matrix of "n" buildings with the following characteristics:
-All buildings in each cell are equal and each of them keeps the same Floor Area to Perimeter ratio as in the real urban fabric contained within each cell.
-Similarly, each building has the same proportion of façades facing the main orientations in each cell as in the real sample. Four main orientations were initially defined in two 90 degrees' axes. The actual azimuth of each orientation reflects the prevailing ones in the urban fabric.
-Crucially, the built-up area and the perimeter of the archetype buildings in each cell coincide with that obtained for the actual urban blocks in the area covered by that cell.

3.2 Building attributes

In practical terms, the grid is a spatial database in which rows represent the cells of the grid and the columns contain the attribute fields. In order to enable interactive mapping, the table must include urban and building parameters. The former includes GSI, FSI and Orientation attributes as well as the compactness ratio, which is the relation between the exposed envelope and the total built area. As for building parameters, the model takes into account building use, construction specifications, window to wall ratio and thermal inertia. Although the model can be updated whenever new data sources become available due to its seamless interaction with geospatial data infrastructures default parameters are assigned where information gaps exist. . The predefined values are taken from bibliographical references and technical construction documents. For its automated assignment, a correspondence will be established between the known data of the urban fabric (e.g. date of construction, location, typology) and the parameters to be entered (e.g. thermal insulation, window ratio).

3.3 Thermal and lighting calculations

The third module of the model focuses on the specific energy demand calculation. It applies a sequential process to obtain the estimated average demand for heating, cooling and lighting. The calculation steps are based on a stationary model and it is applied on the archetype building of each cell of the grid:

1- Calculation of heat losses through the envelope. Total conductive and convective losses are estimated and divided by the built up area to obtain the Heat Loss Coefficient (HLC) in W/m²K.

2- Heat loss per hour. The hourly heat losses are calculated based on the difference between the indoor comfort temperature and the outdoor temperature, multiplied by the Heat Loss Coefficient ((Ti-Te) * HLC).

3- Internal heat gains. Internal casual heat gains are determined for each type of building according to predefined schedules derived from literature [26], [27]

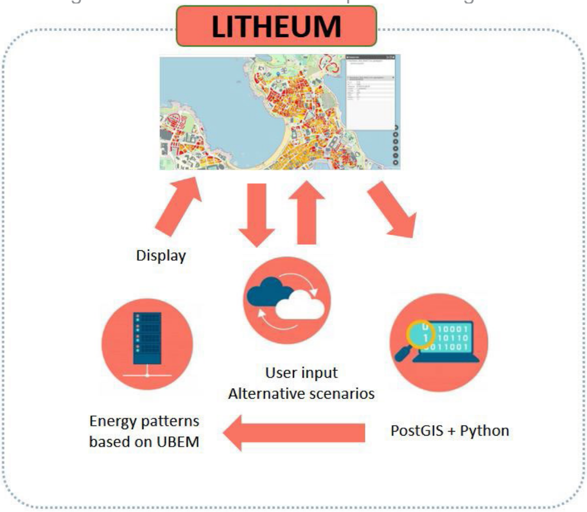
4- Solar gains. Direct, diffuse and reflected solar gains are calculated using a multi-step procedure. First, the vertical solar radiation on each orientation is obtained from the climatological database. We use sun position of the sun and the obstruction angle to infer the hourly direct solar gains on the façade. The resultant value is weighted by the window to wall ratio to obtain the indoor solar gains entering. Similarly, the diffuse solar gains on each façade are calculated based on the weather data, the solar obstruction angle, the glazed area, and the solar transmission values of the glazing. Diffuse solar radiation is considered to be isotropic, that is, constant, throughout the external environment. Finally, we consider that in dense urban areas, reflected solar radiation can be significant. The reflected gains are obtained from the reflection values of the surrounding surfaces, the solar geometry and the angle of obstruction of the facades.

5- Utilization factor. The total solar gains are weighted with the utilization factor, which is the ratio between the useful solar gain and the total gains. We apply a function derived from correlations proposed by [28]

6- Space heating/ cooling demand. In the next step, we compare the heat gain to loss balance, together with the outdoor temperature, to obtain hourly estimates of the indoor temperature. If the resultant value is above or below the comfort range a heat/cooling load is added accordingly. The total annual loads are obtained by iterating this procedure.

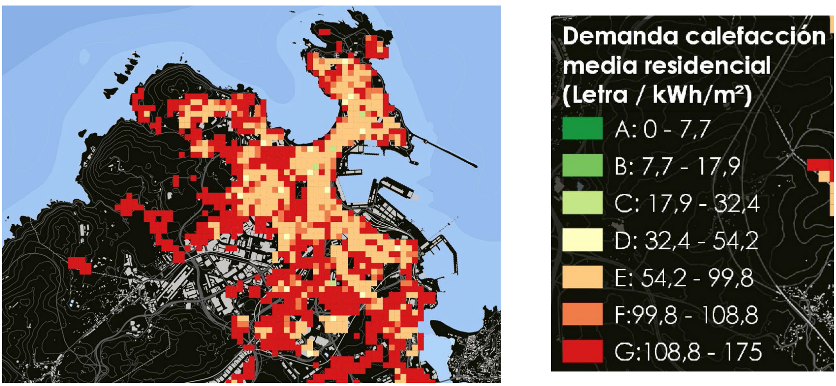
7- Daylight Factor (DF). The model assumes that the living spaces are side lit, so the approximate estimation method proposed by the Building Research Establishment [29] is applied. The average Daylight Factor is defined for the virtual building of each cell of the analytical grid. The values needed for the calculation can be derived from the spatial data or assume the predefined parameters: (a) window area in each façade, (b) obstruction angle, (c) glazing solar factor, (d) floor area and (e) average reflectance of interior surfaces (floors, walls, ceilings). Then, we obtain the external illuminance from the climatic data and establish the need for additional artificial lighting [30] . The internal spaces are divided into passive and active zones as in Baker and Steemers [31]. The indoor illuminance is obtained by combining DF and outdoor illuminance. When it is below the required levels artificial lighting will be added in the passive zone. The energy demand value associated with artificial light is obtained by means of an estimated lighting power per square meter and the hours of use required.

Fig. 4 Structure of the Litheum platform integration



The resultant heating, cooling and lighting loads are stored in the spatial database so it can be displayed in interactive maps thus providing insights of the energy demand patterns of the city. Users of this platform can modify the predefined values (construction type, window proportion, etc…) to evaluate the potential variations derived from energy conservation measures. The structure of the platform is divided into two modules (Fig. 4). After the energy demand patterns have been calculated they are stored in a GeoJSON layer and uploaded into a geoportal, which operates as frontend, displaying the information and prompting the dialogs for users to define queries (retrofit scenarios). In the backend we use a postGIS database and Python scripts to update the energy calculations for the scenarios defined by the user, which are uploaded and visualized into the geoportal (Fig. 5).

Fig. 5 Example of Litheum model applied to A Coruña



4. CONCLUSIONS

This paper describes a research project to develop an interactive portal to display urban energy demand patterns for the building stock of cities. First, it established the state of the art in Urban Building Energy Models. Then, it described the concept of the approach and, finally, it showed an example of the possible uses of this tool. The Litheum tool's innovative approach enables online user interaction on a thermal model that takes into account the specific characteristics of the building and urban fabric.

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Six aspects of social value that already BREEAM can support through the application of the standard BREEAM ES urbanism

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Key Words: Social Infrastructure, BREEAM, Social Impact, Social Value, Social Equity

0.ABSTRACT

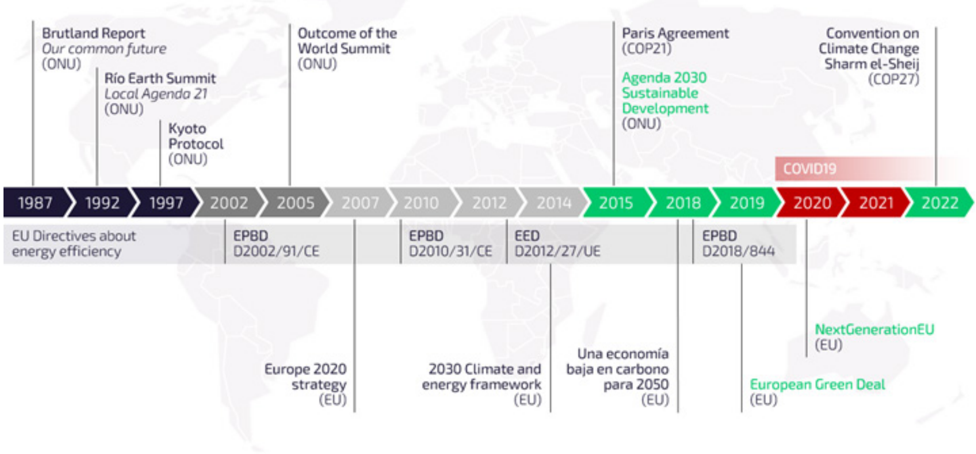
Climate emergency and recent global events have drawn a spotlight on the deep-rooted inequalities that still exist in all communities and societies around the world. How the places are planned, built, maintained and operated have direct impacts on the health and wellbeing of people, the strength of local communities, the economic growth and the planet. Cities need social sustainability, because are crucial for the development and maintenance of social connections and happiness, in a climate change era. Social Sustainability has become the centre point of the debate nowadays.
This paper focus on how the methodology BREEAM ES Urbanism should proactively encourage positive social impacts through the creation of a “social infrastructure” that provides universal and equal access, dignity and fair treatment to people in addition to addressing and mitigating environmental impacts, and creating communities for equity and resilience. The objective of this paper is identified those manual´s Assessment Issues that already are guarantee of addressing social aspects if applying BREEAM ES Urbanism Methodology.
The approach is based on the analysis of the manual itself, and the previous work made by the Social Impact Core Technical Team (CTT) of BRE. This working group was created in 2019 and it has identified six aspects of social value to improve the social impact and value outcomes delivered by the BREEAM standards. These six keys “themes/aspects” of social value are: 1. Health and wellbeing & security of the community; 2. Inclusivity, equitability & accessibility; 3. Stakeholder participation & engagement;4. Behavior change & awareness raising; 5. Responsible leadership & business ethics and 6. Protecting & enhancing local cultural & heritage aspects.
We first evaluate these 6 themes into the methodology, addressing a mapping of the scheme. To do that, we elaborate a scheme mapping to go through those specific issues of the methodology BREEAM ES Urbanism that are most relevant to support these six aspects of social impact and value from the built environment.
As conclusion, we can say that BREEAM ES Urbanism methodology already has a 72% of Social Impact credits, which means that this scheme is the most aligned with social infrastructure and social value of all the BREEAM family.

1.INTRODUCTION

1.1.Towards a paradigm shift

Over the past decades, the international community has identified and tried to mitigate, with varying success, a large number of global environmental, economic, and social issues. Thus, several manifestos, agreements and regulations have arisen that, in some way, reflect the aspirations of international politics to reduce polluting emissions, close the energy gap, increase health and well-being, plan social activities or achieve economic harmony and environmental.

Fig. 1: Chronology of agreements, regulations and policies on sustainability worldwide. Own elaboration BREEAM ES, 2022.



The adoption of the Paris Agreement in 2015 [1] by a large number of countries and the 2030 Agenda for Sustainable Development, adopted by the UN General Assembly months later, have clearly marked this determined commitment to address the challenges key global issues we face, such as climate change, environmental degradation, and socio-economic issues such as health and well-being, inequality, and justice, with the vision and goal of a better and more sustainable world for all.
The 2030 Agenda [2] has 17 Sustainable Development Goals (SDGs), which are being a real success at the pedagogical level and with international repercussions, constituting a roadmap for countries and their societies to build a sustainable future through a series of measures that they include everything from the elimination of poverty to the fight against climate change, quality education, equality between women and men, the defense of the environment or the design of our cities.
In addition, the roadmap towards a decarbonized economy approved by the EU in 2018, the Green Deal [3] signed the following year, or all the recent recovery measures after the COVID-19 pandemic (NextGenerationEU [4]) represent the acceleration of this process of change and highlight even more, if possible, the importance of using an evaluation methodology such as BREEAM ES Urbanism [5], thanks to which we can address global problems through spatial planning.

1.2. Towards a paradigm shift from the social point of view

Many organizations seek to align their activities with these international initiatives, such as the United Nations Sustainable Development Goals (SDGs). Similarly, more and more companies are using environmental, social and governance (ESG) factors to assess the success with which they have introduced sustainability strategies to improve their behavior and results, to manage risk and, ultimately, to increase commercial value. Consequently, consideration of social impacts is now becoming an intrinsic part of decision making, rather than an optional requirement.
The expectation that the built environment should generate tangible benefits for society has become widespread. investors, owners, governments and other stakeholders are increasingly recognizing the need to better understand the social impacts of the built environment. However, there is currently no consistent framework that provides an agreed definition or methodology for measuring social impacts related to the built environment.

The aim of this document is to identify BREEAM's understanding of social impacts, value and equity from the perspective of the built environment and to describe how the BREEAM ES Urbanism [5] standard addresses social impacts.

1.3.BREEAM® family. Why and what for BREEAM®?

BREEAM® (Building Research Establishment Environmental Assessment Methodology)[1] is the most technically advanced method of evaluating and certifying sustainability in buildings and is the world leader in terms of the number of certified projects since its creation in 1990.
BREEAM has helped to improve the environmental performance of buildings and land developments from the design stage, through construction, use and renovation or rehabilitation. In addition, it serves as a best practice guide with a holistic approach to address ESG, Health & Wellness and Zero Emissions goals. BREEAM is owned by BRE[2] , a not-for-profit organization with over 100 years of experience in construction research and scientific knowledge.
Our vision is of a built environment that goes beyond fit-for-purpose, to one that is socially responsive and consciously contributes to long-term economic growth, the health and well-being, resilience and cohesion of people. and the communities.
We seek to strengthen this vision through the following actions:

1. Encouraging social impacts and equity to be a key consideration at each life cycle stage of the built environment
2. Driving the delivery of positive social impacts and value as an output from the development and operation of built environment assets.
3. Contributing to and encouraging industry innovation in the assessment and measurement of built environment related social impacts.
4. Rewarding built environment assets that generate positive social impact and value.
5. Incentivising the development and operation of socially equitable places.

2.SOCIAL INFRAESTRUCTURE

2.1.Social Impact Technical Working Group (TWG)

The BREEAM family of standards, including CEEQUAL and the Home Quality Mark (HQM), have always included requirements that cover various social sustainability issues that lead to positive social impacts and outcomes. In 2019, BREEAM established a Social Impact Technical Working Team (TWG)[3] to identify opportunities to improve the social impact and value outcomes delivered by the BREEAM standards. Our work to date has included:

1. Identifying which BREEAM issues contribute to a positive social impact and the extent of that contribution for each of the current versions of the BREEAM standards.
2. Engaging with and listening to our stakeholders in this space across multiple countries, each with their own social impact and equity issues and societal stresses, to understand how they see where BREEAM could support positive social outcomes in communities everywhere.
3. Acknowledging areas where the BREEAM team need to work to actively expand our own, and the wider sector's understanding of these complex issues.

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[1] BREEAM® (Building Research Establishment Environmental Assessment Methodology), https://bregroup.com/products/breeam/
[2] BRE® https://bregroup.com/
[3] BREEAM Technical Working Group Membership Application: https://bregroup.com/a-z/breeam-technical-working-group-membership-application/

4.Considering who is not represented in our stakeholder space and actively seeking to engage those who are underrepresented to include their views.

2.2.Terms

During this time of work of the Social Impact Technical Working Group (TWG) the definition of terms of social value has been agreed to guide actions under a common prism, as it is showed in the briefing paper Encouraging positive social impact and equity using BREEAM [6]. These definitions are part of the work process that is ongoing and will likely be refined and updated over time as the construction industry begins to reach consensus on the scope and detail of these terms:
Social impacts are the effects on people and communities as a consequence of a built environment related action or activity. Communities include existing residents, businesses and other stakeholders in the local area and all those who interact with the place both now and in the future.
Social value is the cumulative benefit of all social impacts from the built environment to individuals, communities and local businesses.
Social equity is the equitable access of all people to resources and opportunities and full participation in the social and cultural life of a community regardless of their background, e.g. age, gender, ethnicity, culture, socio-economic status, sexual orientation or perceived abilities. Social equity first requires the recognition of the inequities that exist in our societies in order to develop and implement practices that address them.

2.3.Aspects of Social Value defined by the Social Impact Technical Working Group (TWG)

In this process, we have initially identified seven aspects of social value that BREEAM can support through the application of our standards. These aspects have evolved to 6, and they are the ones that we are going to take into account for the development of this study.

1.Health and wellbeing and security local communities: The objective is to promote a built environment that promotes that ensures a physical, social, intellectual and emotional wellbeing.

2.Inclusivity, equitability & accessibility: It seeks to promote the design and operation that favors environments usable by all people, to the greatest extent possible, and without the need for adaptation or specialized design. The goal is to ensure that the needs of the community are met fairly, with equity, diversity, and inclusion at the heart of the project.

3.Stakeholders' participation & engagement: It seeks to take the community into account in the design process to integrate the opinions of the different parties involved in decision-making. It also contemplates the development of community outreach and awareness activities.

4.Behaviour change and awareness raising: This aspect of social value is aimed at developing solutions that encourage people to make the most sustainable option. Behavior change is the transformation or modification of human behavior and can include all activities involved in stopping existing patterns of behavior and adopting new ways of acting. Design for behavior change is an overtly values-based approach that seeks to promote ethical behaviors and attitudes within social and environmental contexts. Sensitization is a process that seeks to inform and educate people about an issue or problem with the intention of influencing their attitudes, behaviors and beliefs towards the achievement of a defined purpose or objective.

5.Responsible leadership & business ethics: Its objective is to promote the development of decisions free of corruption, employment opportunities and skills development, fair wages and working conditions including safety and health, and the well-being of employees and the entire supply chain.

6.Protecting & enhancing local cultural & heritage aspects: Promotes the protection of local culture and environment. Its objective is to protect cultural heritage from the perspective of human rights.

3.BREEAM ES URBANISM

3.1.The manual: Categories, weightings, assessment issues and sustainability criteria

BREEAM ES Urbanism is articulated through a Technical Manual [5] structured into 6 categories, which are: Governance, Social and economic well-being, Resources and energy, Land use and ecology, Transport and movement, and Innovation.

Fig. 2: BREEAM® ES Urbanism categories. Own elaboration, 2020

The absolute categorization of sustainability requirements is complicated, since all three dimensions of sustainability (social, environmental and economic) are often involved. Therefore, by assigning categories, BREEAM seeks to clarify the purpose of each requirement. The categories are listed below with a brief description of their main purpose and the corresponding weighting:

Fig. 3: Objectives and weightings of the BREEAM ES Urbanism categories. BRE, 2012.

Categoría	Objective	Ponderación
Governance (GO)	Promotes community involvement in decisions affecting the design, construction, operation and long-term stewardship of the development.	9,30%
Social and economic wellbeing (SE)	Local economy: To create a healthy economy (employment opportunities and thriving business).	14,80%
	Social wellbeing: To ensure a socially cohesive community.	17,10%
	Environmental conditions: To minimise the impacts of environmental conditions on the health and wellbeing of occupants.	10,80%
Resources and energy (RE)	Addresses the sustainable use of natural resources and the reduction of carbon emissions.	21,60%
Land use and ecology (LE)	Encourages sustainable land use and ecological enhancement.	12,60%
Transport and movement (TM)	Addresses the design and provision of transport and movement infrastructure to encourage the use of sustainable modes of transport.	13,80%

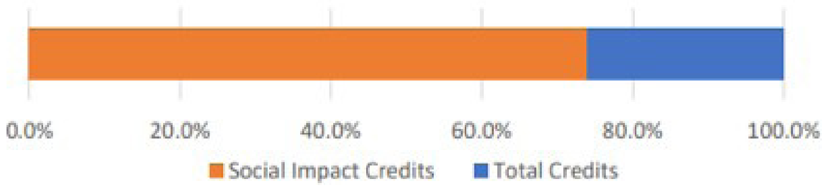
The aim of the categories is an important aspect of the BREEAM ES Urbanism weighting system. The category weights have been established by determining the impact of each category in relation to three pillars of sustainability: social, economic and environmental. These three pillars receive the same value in the manual. Once the weight for each category was calculated, the individual assessment requirements were also weighted by prioritizing according to the importance of each assessment requirement in terms of its impact on the overall objective of the category.

The category “Social and economic well-being” is divided into three subcategories for weighting. This ensures that the weights are based on clearly defined objectives, namely Local Economy, Social Well-being and Environmental Conditions.
Each category, in turn, is subdivided into sustainability requirements. Each of the forty assessment requirements is individually weighted and assigned a variable number of points. This means that the point value varies based on the weighting of the assessment requirement. Each of these requirements includes a series of specific evaluation criteria, through which requirements are detailed, compliance with which qualifies the sustainability of an urban development. Also included are “Additional Notes”, which provide information to facilitate the application and interpretation of each criterion, and an “Evidence” section indicating the type of information required to justify compliance.
It is precisely this organization “from the general to the specific” that allows, from a planning document such as a Partial Plan, to carry out an analysis at a detailed level in relation to very specific issues in terms of sustainability, facilitating the establishment of certain technical requirements, but always respecting a holistic vision from the social, environmental and economic point of view.

3.2. Mapping between 6 aspects of social value and the assessment issues, categories and criterias of the manual

This section addresses the mapping of the 40 requirements of the manual against the 6 aspects of social value identified by the Social Impact Technical Working Group (TWG).
Based on the criteria defined for each requirement in the manual, levels of compliance can be granted for the creation of social value. A qualification scale of the contribution of the ES Urbanism requirements has been defined in 4 levels of compliance, which are: 1. Total contribution, 2. Significant contribution, 3. Partial contribution, 4. Limited or indirect contribution, which refer to requirements related to environmental or economic aspects mainly.
After carrying out this crossing, it has been determined that 72% of the points in the manual provide the creation of social value, while the remaining 28% do not address it clearly and directly. This percentage refers to requirement criteria in the manual that specifically address issues related to environmental and economic sustainability. However, within the requirement itself, there are other criteria included in the percentage of social value. In this way, it can be concluded that 100% of the requirements provide a holistic and integrated approach.

Fig. 4: Urbanism and social impact credits in total BREEAM ES Urbanism scheme. BRE, 2021.

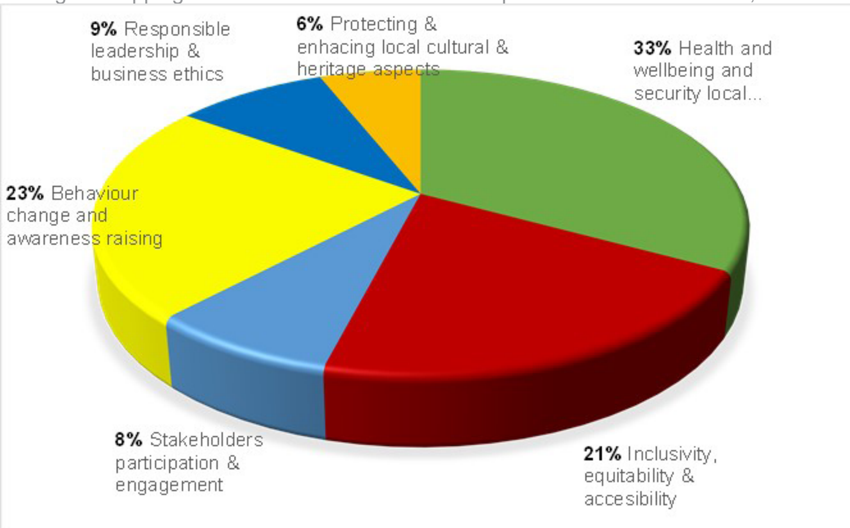


As can be seen, all aspects of Social Value identified in the Social Impact Technical Working Group (TWG) receive a significant contribution through compliance with at least one of the requirements included in the BREEAM ES Urbanism scheme, if well, in general terms, practically all of these have a significant and sometimes simultaneous impact on several of the topics.

Fig.5: Classification of the contribution of each requirement to each aspect of social value. Own elaboration, 2023.

The alignment of BREEAM ES Urbanism with the themes of Social Value is especially significant with regard to Health and well-being and security of the community, since 33% of the points directly impact this issue. For Changes in behavior and awareness, the percentage of credits that address these issues is around 23%, while for Inclusivity, equality and accessibility it is 21%. For the other three themes, the remaining 26% is distributed.
This highlights the clear social focus of the methodology, which seeks to create inclusive and cohesive developments that, through the creation of a solid social infrastructure, are capable of facing new scenarios linked to the climate crisis.

Fig. 6: Mapping BREEAM ES Urbanism with 6 aspects of social value. BRE, 2021.



The Social Value aspects identified in the Social Impact Technical Working Group (TWG) are listed below, pointing out some sustainability requirements of BREEAM ES Urbanism whose contribution is total or significant.

Fig. 7: Mapping og assessment issues criteria and 6 aspects of social value. Own elaboration, 2023

1.Health and well-being and security of the community: seeks to promote that the built environment ensures physical, social, intellectual and emotional well-being. This is one of the key objectives of the manual and in all categories, specific requirements and criteria are addressed, to a greater or lesser extent, that pursue the creation of sustainable communities. This is why 33% of the points in the manual have a crossover with this aspect.
The BREEAM ES Urbanism category that has the greatest impact on it is “Social and Economic Well-being”. This category takes into account the environmental, social and economic factors that affect health and well-being, such as inclusive design, cohesion, the availability of adequate equipment and housing or access to employment. It has so much weight and importance within the manual that it is divided into 3 subcategories to specifically address “Local Economy”, “Social Well-being” and “Environmental Conditions”.
The first subcategory focuses on economic aspects, and therefore the crossover with this aspect is not direct. In fact, it is for the other two.
The “Environmental Conditions” subcategory seeks to minimize the impact of environmental conditions on the health and well-being of the occupants. Requirements such as SE 08 Microclimate, and SE 10 Adaptation to climate change, are examples of this. SE 08 Microclimate encourages urban development to provide a comfortable outdoor environment through the control of weather conditions on a small scale, and for this the design proposal must optimize weather conditions throughout the year, for example, pedestrian routes and for Cyclists should always take microclimatic conditions into account. SE 10 Adaptation to climate change, seeking to investigate the different risks associated with climate change with the aim of guaranteeing the resilience of urban development in the face of the known and expected impacts of climate change.
The “Social Well-being” subcategory aims to guarantee a socially cohesive community. In this category, requirements standout such as SE 06 Provision of equipment, services and facilities, SE 07 Public space, SE09 Utilities and SE11 Green infrastructure, which aims to guarantee access for all to high-quality spaces in the natural environment or infrastructure urban green. Each of the requirements details compliance criteria and additional notes that provide information on how it should be addressed. Also deatials, additional information and the necessary evidence to justify its compliance.

2.Inclusion, equity & accessibility: it seeks to promote the design and operation that favors environments usable by all people, to the greatest extent possible, and without the need for adaptation or specialized design. All the categories, except for “Resources and energy”, address these issues, accounting for 21% of the points, although there are two categories, “Social and Economic Well-being” and “Transportation and Movement”, which do so more direct.
An example of a requirement that addresses these issues is found within the category “Social and Economic Well-being”, and specifically the subcategory “Social Well-being”, it is SE15 Inclusive Design. The goal of this requirement is to create an inclusive community by improving accessibility for as many existing and future residents as possible. This requires the preparation of an operational management strategy and an inclusive design at the beginning of the project to incorporate elements of accessibility, inclusion and emergency evacuation of all occupants and visitors, specifically taking into account the well-being, age, gender people’s ethnicity, beliefs, and special disability needs. As long as a responsible member of the design team is also appointed to advocate for and oversee inclusive design during masterplan planning, we are eligible for a higher score, which would further be increased by appointing an independent accessibility consultant and their Recommendations are incorporated into the masterplan and used as the basis for informing the operational management strategy.

3.Participation & commitment stakeholders: This topic of social value addresses taking the community into account in the design process to integrate the opinions of the different parties involved in decision-making. Also, the development of community outreach and awareness activities. In this case, the BREEAM ES Urbanism manual develops a specific category, that of “Governance”, which accounts for 8% of the points, along with other requirements from different categories, which also indirectly or partially promote it. It focuses on promoting community participation in decision-making that affects the design, construction, operation, and long-term management of urban development.

The GO 01 Consultation Plan requirement lays the foundations to guarantee the participation of interested parties throughout the design, planning and construction process, and to a lesser extent its subsequent maintenance. This requirement also identifies the different requirements of the manual that require consultation, and therefore should be addressed early enough in the process to allow the community and stakeholders to influence key decisions. Other requirements are GO 02 Consultation and Participation, GO 03 Design Review, and GO 04 Community Management of Facilities. This governance category constitutes a solid and very stable base to create a true social infrastructure in each and every one of the phases of urban development, from design to occupation and subsequent maintenance.

4.Behavior change and awareness: Design for behavior change is an overtly values-based approach that seeks to promote ethical behaviors and attitudes within social and environmental contexts. Sensitization is a process that seeks to inform and educate people about an issue or problem with the intention of influencing their attitudes, behaviors and beliefs towards the achievement of a defined purpose or objective. In this way, it seeks to develop solutions that encourage people to make the most sustainable option. In the manual, the percentage of points that share this objective and develop criteria to carry it out is the second highest, of the 6 aspects of social value identified, assuming 23%, since it covers different requirements of the different categories. . Transport requirements such as TM 02 Safe and appealing streets or TM 04 Access to public transport, address design issues and also services that create healthy habits in people. For example, TM 02 seeks to create safe and attractive spaces that encourage human interaction and a positive appreciation of the environment. And for this it is necessary to base the design objectives of the image of the streets. Also, the development of a context assessment to determine the most appropriate distribution of the image of the streets in relation to existing or planned buildings, as well as open spaces. And a mobility framework program to determine the distribution and design of the image of the streets to promote sustainable modes of travel and transport with the help of mobility plans.
Also requirements of the “Land Use and Ecology” category such as LE 02 Land use, LE 04 Improvement of ecological value, and LE 05 Landscape, contain criteria that encourage this change in behavior and awareness in relation to respect for the character of the landscape. through a selection of species, practices and design appropriate to the local environment.

5.Responsible leadership and business ethics: promotes the development of decisions free of corruption, employment opportunities and skills development. Fair wages and adequate working conditions, including the well-being of employees and the entire supply chain. It has been identified that 9% of the points respond to this approach, which is developed mainly in the requirements of the “Local economy” subcategory. Specifically, the requirements SE 01 Economic impact and SE 17 Education and training whose objective is to guarantee the contribution of urban development to the local area by improving professional skills and training opportunities.

6.Protection and enhancement of local culture and heritage issues: seeks to protect cultural heritage from a human rights perspective. In the manual, requirements have been identified that account for 6% of the total score. Below are two from different categories. On the one hand, SE 14 Typical local architecture, within the subcategory “Social well-being” of “Social and economic well-being” whose objective is to create communities that respond to the local character while reinforcing their own identity. For this, the development of a consultation and a study of the local character is required to determine important elements to incorporate in the design of the site. On the other hand, the RE 02 Existing Buildings and Infrastructures requirement, from the “Resources and energy” category, is another example, with another approach, in which an assessment of existing buildings and infrastructures is required to determine which ones can be rehabilitated, be reused, recycled or maintained, as well as which have significant value, taking into account heritage and local identity.

4.CONCLUSIONS

Summarising, we can affirm that the social approach, of social sustainability, is key and will define the roadmap in the nearest future. The challenges are many and the objectives ambitious, but it seems that we are finally on the path to addressing and incorporating them in a clear, agile, efficient and sustained manner over time. In this sense, certification methodologies such as BREEAM ES Urbanism are becoming extremely useful and innovative tools, facilitating this transition.
After carrying out the analysis of the methodology against the 6 aspects of social value, it is determined that 72% of the points in the manual provide the creation of social value, while the remaining 28%, although they do not address it clearly and directly, does refer to criteria requirements in the manual that specifically address issues related to environmental and economic sustainability. But, within each requirement of the different categories, there are other criteria included in the percentage of social value. In this way, it can be concluded that practically all the requirements provide a holistic and integrated approach.
By proposing a holistic and detailed approach to the development and management processes of our urban areas through 40 requirements collected in different categories (Governance, Social and economic well-being, Resources and energy, Land use and ecology, Transport and movement and Innovation), and regardless of whether or not you choose to obtain a certification, the BREEAM ES Urbanism application allows you to go into detail, guide you in what and how, and also serves to measure and demonstrate the impact of the measures of social sustainability applied.
In short, BREEAM ES Urbanism is a guarantee that sustainability is addressed in an integrated manner, and that the inherent flexibility of the manual allows new additional notes to be included in it that detail key issues for the creation of social infrastructure. In this way, the guiding nature and best practices of the BREEAM methodology are reinforced.
Undoubtedly, the work that the Social Impact Technical Working Group (TWG) has been carrying out since 2019 will return more robust methodologies after adapting the existing BREEAM requirements to improve their social value and equity results.

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Next Generation renovations under the microscope: a failure or success?

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Key Words: building renovation, Energy policy, Decarbonization, Energy poverty, Renovation management.

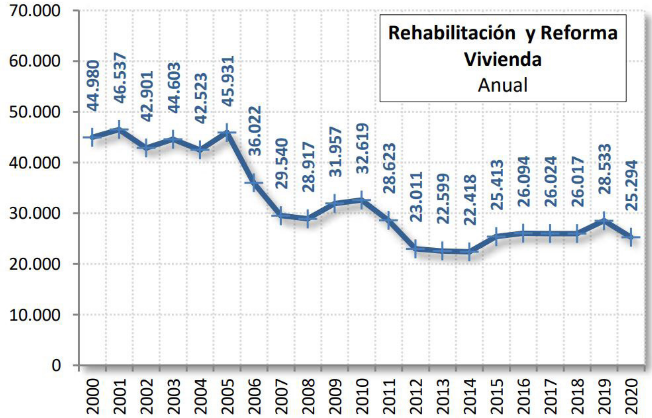
0.ABSTRACT

The need for accelerating building renovations has driven European regulations in the last decade. After the COVID-19 crisis, the European rescue plan dedicated a very significant amount to promote existing building decarbonization. These public investments, also known as Next Generation grants, were published in the Spanish regulation framework in 2021 and offered financing for renovations through six main programs that can cover more than half of the investment costs. The most relevant program funds renovations that could justify reductions of 30% in heating and cooling demand and savings in non-renewable primary energy, to reach three main objectives: 30%, 45%, or 60%. However, despite this comprehensive economic support, the Spanish society is still hesitating to conduct these major renovations and the agents or participants in these processes are struggling to achieve the renovation goals.
Under this challenging scenario, this study analyses the reasons behind this lack of action in the building renovations and formulates future improvements that could help speed up the current renovation ratios. To do that, a workshop was organised with all the actors involved in these processes to share and evaluate the building renovation difficulties during the Next Generation EU funds. This event was coordinated by the Basque Government's Laboratory for the Quality Control in Buildings on the 21st of March of 2023 in Vitoria-Gasteiz. The workshop gathered more than 90 participants and experts from different stakeholders.
The results of the workshop describe the situation of the sector in detail. First, a detailed analysis of the current situation of the building renovations and the grant numbers was done, compared to the existing literature. Also, the expected numbers, dates, and planned scenarios. Second, the ideas commented on in the two round tables were studied following the seven chapters or sections, which include the experience of different stakeholders, administrative procedure, financing, stakeholder communication, technical requirements, quality control of the works, and future perspectives. One of the most interesting outcomes was the identification of the main barriers that hinder building renovations. These difficulties and/or limitations were listed and sorted by their relevance.
Additionally, as the event was broadcasted live, there was an online communication tool to help gather comments from more than 40 online participants and complemented the debates of the round table and the room audience. This online tool included a survey to make a quantitative assessment of the previous questions, and the answers from 42 participants outline the situation and underline the debates of the workshop.
After the event, there was a post-processing process of the data using the survey, the video recording, and the notes from the workshop. Among others, the lessons learned from the participants are highlighted and the future potential improvements are described.
The conclusions of this workshop and the ulterior study are relevant as they show the ugly truth of the renovation sector and help identify success stories and failures, that must be overcome if we aim to achieve decarbonization before 2050.

1. INTRODUCTION

Recent literature shows that the renovation wave is not reaching Spain properly. Between 2012 and 2016 the deep renovation ratio was around 0.3% of the weighted floor [1]. The first long-term strategy for building renovations in 2014, called ERESEE [2], did not get the expected results. Furthermore, the latest studies evidence that this ratio was slightly improving in 2019 before the COVID crisis, as shown in Figure 1 [3], but far from the EU ambition of 3%.

Figure 1. Evolution of housing refurbishments and renovations in Spain 2000-2020



However, the Basque region's situation is somewhat different. For a decade the regional government promoted deep renovation grants like RENOVE [4] and helped improve the whole sector. As a result, the renovation rate increase is clear and regular since 2014, as depicted in Figure 2, reaching a very significant 1.5% in 2022 [5]. Despite this success, there are still some barriers and difficulties that hinder the increase of building renovations. The region's agents have recently signed the Social Pact for Housing 2022- 2036 [6] to commit to future steps from the public and private sides.

Figure 2. Evolution of building licenses in the Basque Country 2005-2022

Regarding the EU NG grants, up to 80% of funding was offered for building renovations with deep PE reductions and offer six programs to boost renovation. In June 2023, the Basque government announced that the NG building renovation goals were achieved in terms of the allocated budget. This confirmed the observed good trend and time will tell how the benefits are in the long term. The present work analyses the reasons that hinder building renovations under the current NG grants and formulates future improvements to increase the present 1.5% renovation ratio.

3. METHODOLOGY

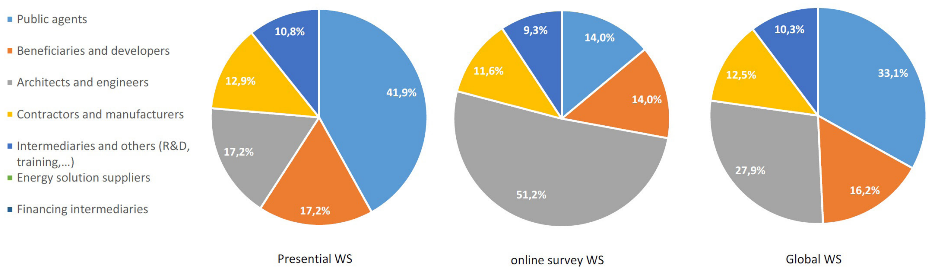
An exploratory workshop [7] was organized with all the actors to evaluate the building renovation difficulties in the context of NG grants. The event gathered experts from different stakeholder categories, and it was celebrated on the 21st of March of 2023 in Vitoria-Gasteiz, in person and online. The debates were guided with key questions and led by a team from the Basque Government's Laboratory of Quality Control in Buildings. After the event, the evaluation of all the data from the survey, the event video, and the notes allowed us to draw out conclusions.The program included:

- Analysis of the current strategy for residential building renovations, grant numbers, and future goals.
- Building renovation examples in literature and quality control of the works
- Round table 1 to analyze NG grants management, focused on the public sector.
- Round table 2 to analyze housing renovation situation and NG grants, focused on the private sector.
- Online survey to gather wider views and numerical assessment of the situation and NG grants.

4. WORKSHOP RESULTS AND DISCUSSION

The attendance at the face-to-face workshop comprised 93 people in person and 43 answers to the online survey, that makes a total of 136 people. Each participant was identified during the registration of the event, and they declared their role in building renovations using the 7 categories previously defined in the methodology. This good attendance level and participation in the debates and survey led to rich debates and relevant takeaways. Below, Fig.3 depicts the participation in the workshop, separating the in person part, the online part, and the global workshop participation, showing the variety of attendance by their roles in building renovation.

Figure 3. Workshop participants and their role in building renovations



As for the presential debates, it is worth mentioning that the most represented category was public agents with 39 people (41.9% of the total). Noteworthy how the next categories had similar representations, namely 16 beneficiaries and developers (17.2%), 16 architects and designers (17.2%), 12 contractors and manufacturers (12.9%), and 10 intermediaries and others. This last category includes 5 from research and R&D institutions (5.4%), 3 from schools of construction skills (3.2%), 1 laboratory of quality control (1.1%), and 1 intermediary (1.1%). There was no representation from the suppliers of energy solutions nor the financing intermediaries. There were more people interested in the presential act, but the meeting room was limited to 100 people for security reasons, so the people exceeding that number were invited to follow the event online and fill in the survey.
As for the online survey, the representation changed significantly as the biggest participation came from the architects and designers with 51.2%, followed by public agents (14.0%), beneficiaries and developers (14.0%), contractors and manufacturers (11.6%) and intermediaries and others (9.3%).

4.1. Current policies for housing renovation

The following three main policies were presented. The representatives explained the global strategy, the building renovation conditions, and the urban regeneration through districts renovation and innovation.

Strategic framework for the renovation of buildings:

The main figures and challenges of the housing stock of the Basque Country were presented, highlighting that Euskadi is one of the European regions with the oldest housing according to the year of construction. A detailed assessment was done by the Basque region experts and political parties, which lead to the strategic lines and actions described in the Social Pact for Housing (2022-2036). This long-term plan aim is to achieve the renovation of all homes (private and public). Among others, the importance of ITEs (Technical Inspection of Buildings) and their obligation in the last decade were reinforced. One of the new lines of aid for construction companies is also on display, “Line 4: creating an attractive, competitive and innovative construction sector”. Its objective is to promote this sector, since around 50,000 jobs were eliminated since the 2008 crisis and its recovery is slow, compared to expectations for future works. Finally, the Next Generation EU objectives for the region in 2022-2023 [7] have already been exceeded, with more than 7,720 homes that have applied for grants to conduct their housing renovations.

Next Generation grants for the comprehensive renovation of buildings:

In a wider context, the housing renovation objective of the Basque Government is to double the rehabilitation rate from the current 1.5% homes per year to 3.0%, to reach the European reference value. This involves a significant effort from the administration and the market. The NG grants can be a boost for the construction sector. The requirements are high, but the economic aids are also significant. In addition, it is emphasized that the regular rehabilitation grants in the Basque region began a decade ago to bet on comprehensive and simultaneous rehabilitation (RENOVE plans or similar since 2013). This option is different from the usual step-by-step rehabilitation and focuses on maximizing the quality of life in the upgraded buildings. Finally, two new initiatives were presented. First, the Thermal and Air Quality Control Order [9] is a new regulation that defines the methodology for the control of the benefits that the Building Technical Code (in Spanish CTE) requires of the main elements of the energy efficiency of buildings. Second, a Plan for inspections of the Next Generation EU rehabilitation works that randomly will be carried out on some of these works, to review the correct construction and raise awareness about quality control in the rehabilitation works.

Urban regeneration: OpenGela program:

Since 2017 the Basque government has promoted the renovation of vulnerable neighbourhoods. This has implied a change of scale and the need to improve care and local accompaniment, through the creation of district offices, such as the OpenGela program (with great recognition at a European level) [10]. The programs developed in this period affected almost 5,000 homes (vulnerable pilot projects, Berpiztu, and PIIE programs) with 150 million euros in aid and mobilizing a total of more than 300 million euros of private and public funds. Numerous proximity actions, meetings, and training courses have been promoted. In a complementary way, the monitoring of indoor conditions and energy consumption has been implemented to know the result of the renovations. These results have facilitated the adoption in other similar buildings and neighbourhoods. As next steps, the OpenGela web tool was presented, a platform for planning, financing, and support in neighborhood scale renovations.

4.2. Building and district renovation challenges

Conclusions of the Annex75 project: district renovation combining energy efficiency and renewables: The IEA-EBC Annex75's main goal is to achieve Cost-efficient renovation of buildings at district level combining energy efficiency and renewables. This project, in which 13 European countries have participated between 2018 and 2023, is coming to an end. The research team analyses how the district scale can improve the possibilities of building renovations and seeks a balance between energy efficiency measures and renewable energies. Apart from a number of journal and conference publications, the main deliverables are available on the project website [11], for instance: the most appropriate technologies for passive, active solutions and renewables; the analysis of success stories; a report with parametric studies; and several guidebooks with recommendations for public agents and for communities of owners, developers, and investors in general. The main conclusions of the study indicate that there are no unique or ideal global solutions, but it depends on the starting situation of each district. The district scale has more potential to speed up building renovation, thanks to economies of scale, centralized or district facilities, and the potential for coordinated management of multiple buildings. Besides, some risks and difficulties of this larger scale have also been identified, such as financing, coordination, stakeholder dialogue, etc. It ends with recommendations, such as Certification at the district level, the importance of One-Stop-Shops (OSS), innovative business models, specialized training, and transparent communication.

Challenges of the new generation of EPC. Data quality and new calculation methodologies:

Data shows that a review of the Energy Performance Certificates (EPC) is necessary. A study [12] carried out on 146 EPC that were controlled by the Laboratory of Quality Control of Buildings, of the Basque Government, showed that they had an average deviation or error of ±40% before carrying out their Control. These errors were symmetrical, both upward and downward, which indicates that it is not a matter of bad intention in their definition, but ignorance or other errors. One of the main findings was that the origin of the errors is relevant. A third of the errors (30%) could have been identified and corrected by automatic checking. During the visits, 25% of the errors were detected. The remaining 45% was detected through a detailed review of the certification file and its documentation. Noteworthy that the greater the energy consumption, the larger the deviation detected. In general, three types of projects had the greatest deviations in the energy consumption per square meter: tertiary buildings (educational, health, offices), the EPC made with simplified calculation tools (CE3x), and existing buildings (with deep renovations up to A, B or C classes). An example of an innovation project to improve EPC was presented, the Smart Living EPC (Advanced Energy Performance Assessment towards Smart Living in Building and District Level) project [13]. They propose four types of certificates, based not only on the buildings' theoretical consumption but on their real consumption too. In addition, the need for offering building and neighborhood scales. This project started in 2022 and they are developing these new CEE models on local examples, searching for pilot cases.

Quality control on site and inspections in NG funded renovations:

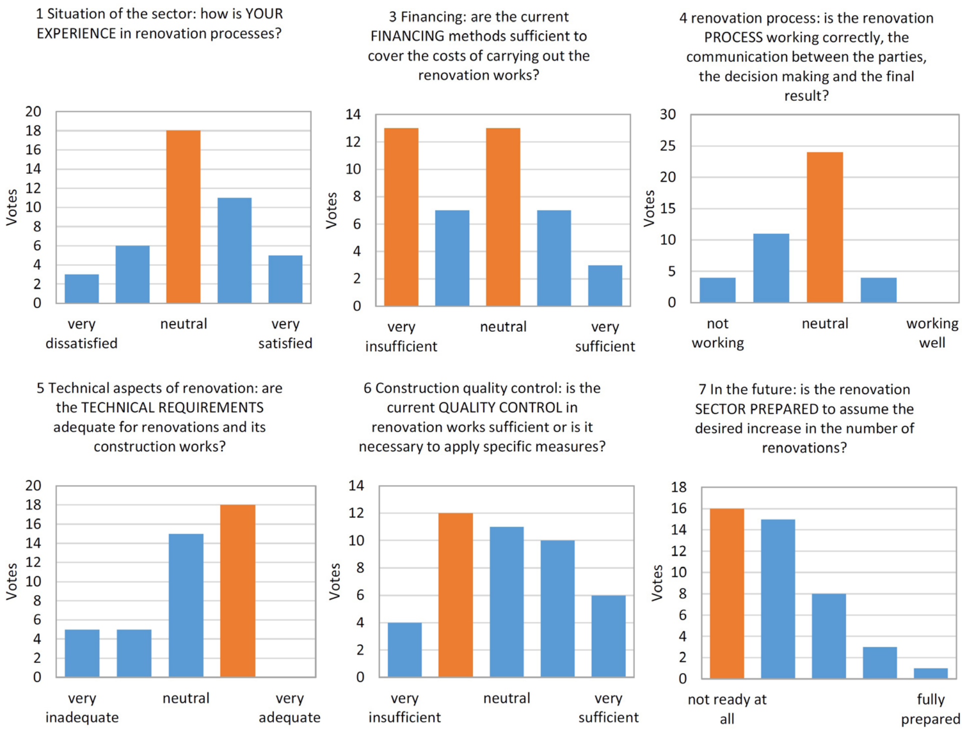
For more than a decade, the Housing Department of the Basque Government has promoted and supported the renovation of residential buildings through different rehabilitation aid programs. Their main objective is to achieve a reduction in the energy consumption of its buildings and, additionally, to improve the quality of life of its users. There are cases in which the quality of the renovation work is not as expected due to different reasons such as poor execution on site, use of inappropriate materials, or lack of quality control in the process. Consequently, pathologies may appear that worsen the energy performance of the building and the living conditions for the inhabitants. For this reason, all the actors involved in the process (developer, project management and construction company) have responsibilities to ensure work fulfils proper quality. The best tools to achieve a good execution of the work are: well-conducted quality control document verifications, construction execution follow-up, and for some key elements also tests.

These measurements can be carried out on-site and in laboratories, like the facilities of the Building Quality Control Laboratory of the Basque Government. Finally, and in line with ensuring proper execution of the renovation works that receive funding from the EU Next Generation funds, the Department of Housing announced that will carry out inspections. The main objective is to motivate stakeholders and get better renovations. These inspections will be done randomly and may also be requested by any agent involved in the renovation (owners, architecture & engineering, contractor, etc.). The review will comprise a documentary review and on-site checks for the main elements that affect the improvement of energy efficiency in buildings, namely the renovated or added thermal insulation, construction insulation solutions, windows, and energy systems.

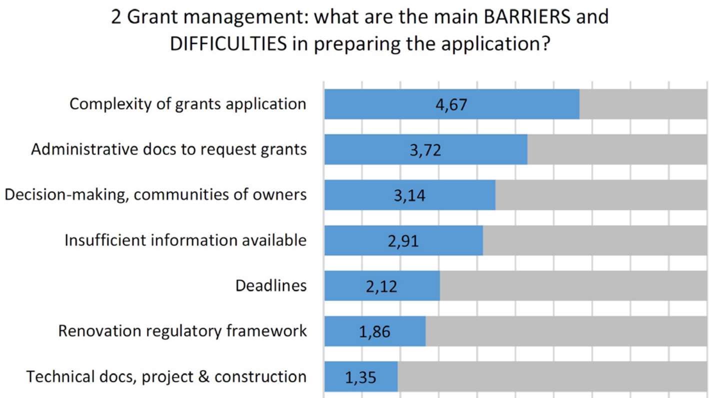
4.3. Online survey feedback

The votes of 43 participants are summarised in Figure 4. These results were shown in the two round tables and they were confirmed by the debate conclusions. Also, the main difficulties and barriers were ordered as shown in Figure 5. Some additional comments were made on certain questions of the survey and helped enrich the debate of the round tables.

Figure 4. Workshop responses gathered with the online survey and identification of the most frequent answers



. Figure 5. Identified main barriers and difficulties in preparing the NG grant application



4.4. Debate on grants management

This debate aimed to discuss the key issues regarding the management and application for the EU NG grants. Noteworthy that participation was led by a table with 6 public agents and one representative of the building managers association, all of them with experience in the management of EU NG grants, from different points of view.

EU NG Grant framework: how do you see the application for renovation grants?

Public institutions shared an overall positive experience, but the experience of renovation processes depends a lot on the environment. Proximity offices can greatly improve the process, a place where all the agents can have a place to arrive and participate together. They acknowledge the large amount of paperwork particularly for the small NG program grants like the windows replacement. These requirements came from Europe.
On the other hand, building managers stated that their experience is not positive, and a little disenchanted. The 4 months to 1 year of waiting time can be very uncertain. When communicating the renovation works in the communities of owners, in their words “First you must have the money for the renovation works and then if the aid arrives, you have won the lottery”. The owners’ family income documents are difficult to obtain.

Grant management: what are the main barriers and difficulties in managing these grants?

From public institutions, the volume of files has been very intense, with around 5,000 files in a year. More than 1,000 have been resolved and the average response time is 6 months as of March 2023. Although the data is not easy to collect, it is necessary to be able to resolve the requests. In general, all the entities are catching up, with certain delays, and seeing that sometimes the documentation is not delivered firsthand as it should.
Building managers state that the grant website is not easy to fill in, requiring too much information in each step. In their opinion, a big part of the requested information should already be in the hands of the public administration. Also, a private owner commented that some agents do not motivate the community of owners. In particular, some building managers explain the grants in a way that no renovation is chosen.

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Public agents underline the importance of building managers in the process. They are the pre-existing interlocutor when willing to convince and accompany this process, which is very difficult.
They also state that must be clear that the promoter of the renovation works is the community itself, advised and informed by their building manager and the technicians they hire. The information available to that community must be improved.

Construction quality control: is the current quality control in rehabilitation works sufficient or is it necessary to apply specific measures?

Public institutions comment that "In the coming years, a quite important renovation movement is coming to us and if we want it to go on the right track, inspections will be very necessary in these works". For building owners' is hard to manage this or to make decisions, they depend on the architecture team. They would like to have a public classification of companies, but this exceeds the current framework.

The future: is the rehabilitation sector prepared to assume the desired increase in the number of rehabilitations?

All participants believe that the sector is not ready. Many times, the communities opt for the price without considering other aspects of work, despite being one of the biggest investments for many of these owners. Other aspects can be as decisive or even more than the price itself. Renovation is often understood as something quick, and it is not. Decisions must be made one by one, first choosing the technician, then the constructive solutions, then the construction company... Additionally, building managers acknowledge that much progress has been made in recent years. The issue of dates is an important barrier to slow decision-making.

4.5. Debate on the challenges from the private sector

The second debate discussed the EU NG grants perception from the private side. The table comprised representatives from building management, architecture and engineering companies, and renovation works contractors. Also, the audience participation was intense, with public agents and other stakeholders.

The situation of the sector: how is your experience in renovation processes?

For some, it is a positive experience, a technical challenge that we are facing, and opens a field of work. The main resource when facing a promoter who has his complexes, with his particularities and even his ideals has been "to be didactic and transparent" and that the project goes step by step.
On the other hand, some construction companies and professionals had bad experiences with renovation work. The market price increase was hard especially for small construction companies that suffered to manage the benefit reductions in turnkey projects.

Grant management: what are the main barriers and difficulties in preparing the grant application?

The short duration of the NG program was the main difficulty. Participants mentioned the short time in 2023 for preparing the documents and gathering personal family income or vulnerability information from the owners. Basque Government representatives mentioned that the calendar is short due to the European frame, and they offered regional grants for renovations, which will continue open for future works as well.

Financing: are the current financing methods sufficient to cover the costs of carrying out the renovation works?

The general perception is that funding is not decisive for the communities to decide to carry out the works. Building managers comment that most of the owners don't ask for a common loan, but their own savings or borrowing from relatives in many cases. Financing institutions are offering increasingly more finance for homeowners because in their opinion "banks realized that the assemblies of owners are not delinquent, home payments are the last thing that people stop paying for". "They may pay late, but they pay". In addition to the grants, some companies are also offering financing, such as ESCO or as some innovative funding solution.

Renovation process: is the renovation process working correctly, the communication between the parties, the decision-making, and the final result?

Architecture and engineering teams reflect on the need for good criteria for choosing the construction company, not the cheapest. A good way would be to establish other specification that not only assesses the economic issue. A document signed by the promoters. Building managers indicate that they have experience in choosing budgets for other technical reasons different from cost, and they got the funding for those without any trouble. They also mention the difficulties of the owners' meetings, especially for the AF, but also for the technicians, and especially due to the short decision times and the high investments that these works usually require.

Technical aspects of renovation: what do you think of the technical requirements of renovation aid and how do they materialize in construction?

The NG grants do not require ventilation quality or overheating prevention justification. All the participants agree on the importance of these aspects. Also, there is a lack of skilled workers, people who know how to place the materials and products. This affects the real-built technical conditions which don't match the average training level of the construction workers. The increase in renovations should be compensated with larger training programs and the improvement of their job conditions.

Construction quality control: is the current quality control in renovation works sufficient or is it necessary to apply specific measures?

Quality control in renovation seems to be sufficient is the other aspects already mentioned before are attended.

The future: is the renovation sector prepared to assume the desired increase in the number of renovations?

There are not enough workers to duplicate the work of current renovations. We should improve and motivate young people in the long term. We should think not so much of the wave of renovation, but of a tide of renovation, a more continuous movement, more sustainable and acceptable to the sector.

5. CONCLUSIONS

The housing renovation situation in the Basque region has improved very significantly in recent years and achieved a 1.5% renovation ratio in 2022. This coincides with the policies and grants established by the Department of Housing that promoted the sector's trust for a decade.
This study consulted a wide range of stakeholders to identify the factors that hinder present housing renovations to reach the European 3% goal, and the applied methodology found consistent results. On the one hand, the main difficulties or barriers in the context of NG funds are related to their administrative side and to the decision-making processes of communities of owners. On the other hand, the lowest barriers are related to the technical documents for project and construction, and to the building renovation legal requirements.
In addition, all the participants stated that the building renovation sector is not ready for the renovation wave and to double the renovation ratio. Among other reasons, the renovation grants short deadlines and the lack of skilled construction workers are mentioned.
To speed up the construction ratio, future recommendations from the public side would be to provide a stable background with stable and longer grants programs, simplify the administrative side of grants, offer more public support, with transparent information and templates for company selection for example, and increase the construction training programs. And from the private side, communities of owners should acknowledge the importance of experienced professionals and building managers to facilitate the decision-making process, and these decisions should consider wider technical aspects rather than the price alone. For construction companies, the working conditions and salaries should be better to attract young people to this sector.

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Geometric and thermal characterization of buildings at urban scale based on open data

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Key Words: Geographic Information System (GIS), cadastral data, geometrical caracterization, U-values, energy simulation.

0.ABSTRACT

The energy renovation in buildings is one of the major challenges for the decarbonization of the building stock. In order to prioritize decision-making in the choice of the most efficient solutions, it is necessary to characterize the behaviour of the building stock and measure the impacts of possible improvements at urban scale. Reaching that point of definition requires setting geometric and thermal characteristics of the stock. In this study, a methodology is developed for the geometric and thermal characterization using open data (such as cadastral data) that is processed through QGIS (Free and Open Source Geographic Information System).

Thus, this study aims to define, in a systematized and sufficiently precise way, the geometric and thermal characteristics of buildings at urban scale to feed later an energy demand model that evaluates the potential for improvement and mitigation through different actions.

This geometric characterization is based on obtaining and processing open data from cadasters to extract, using QGIS, the envelope surfaces by orientation that define the stock. Through the geometric data, the roof surface and the façade and windows surfaces by orientation are obtained. This information contributes to define later the overall thermal conductance (UA) and the south equivalent surface (SES).

In the case of thermal characterization, an automated process is defined, by means of assigning different parameters according to the construction year of each building known from cadastral data. The parameters obtained are; a) U values (to determine the thermal transmittance of each element); b) the g solar factor of the glazing (to determine the solar gains); c) the air renovation due to ventilation and infiltration; and d) the internal gains.

The methodology is applied in a real case study for a given area in Bilbao and the values of the parameters obtained through QGIS are validated with those presented in energy performance certificates.

1.INTRODUCTION

The building sector is one of the largest contributors to energy consumption and emitter of more than one third of greenhouse gas emissions in the European Union. Space heating and cooling accounts for approximately 50% of total final energy consumption in the European Union. [1] Faced with the major challenge of decarbonisation by 2050, the retrofitting of the building stock and the implementation of renewable energies are key actions to achieve energy efficiency. Strategies in terms of building retrofitting shift from focusing on individual building interventions to focusing on building clusters at neighbourhood, district or city scale. It is therefore of particular relevance to work with simple energy demand estimation models at the urban scale, defining the behaviour of existing buildings accurately and in a systematised way, as well as quantifying the impact of possible interventions in order to prioritise actions. To this end, the geometric and thermal characteristics of the buildings must be defined in an agile manner, but with sufficient precision, since the parameters defined will directly influence the results obtained.

The aim of this work is to characterize geometrically and thermally large-scale buildings in a systematised way from open data to then, feed an energy demand model.

1.1.State of art

The geometric characterisation of building stocks from cadastral data and the thermal characterisation of buildings at urban scale has been discussed in several articles, especially in the last decades.
Some of these studies focus on the systematic characterization of buildings at large-scale. Among them, Martín Consuegra et al. [2] explore the use of cadastral data for energy retrofit planning at urban scale in Madrid, Yang et al. [3] use GIS to model space heating energy for residential buildings in the Netherlands, Fernández Luzuriaga [4] focuses his thesis on the characterisation of the residential stock in Bilbao and the technical and economic analysis of energy efficiency measures and the decision making process of homeowners on the refurbishment of their dwellings and Prades Gil et al. [5] develop an agile model of heating and cooling energy demand for residential buildings in Valencia.
Other researchers, meanwhile, classify the construction characteristics of building clusters by analysing samples. Of whom, Oteiza et al. [6] study the envelope of social housing in the outskirts of Madrid for future energy refurbishment; Kurtz et al. [7] specify the building solutions of 21 Spanish post-war Urban Ensembles of Interest in Zaragoza; Calama-González et al. [8] evaluate the behaviour of the H typology of social housing in the south of Spain, one of the most representative building typologies of the social housing stock of the place and for this purpose they carry out the physical, geometric and constructive characterisation of the building and Rodriguez Lorite [9] develops an analysis to present and quantify which physical elements are repeated in different cities based on five case studies (Alcalá de Henares, Almería, Jaén, San Sebastián and Tarragona).
Regarding the constructive characterisation of building stock extended in different locations; there are the TABULA project [10], which assigns building typologies to the building stock of 13 European countries according to parameters such as their size and age and estimates their energy characteristics and possible energy savings through refurbishment; the ENTRANZE project [11] that works on building characteristics, scenarios and recommendations to support policy formulation and the Manual of technical fundamentals of energy rating of existing buildings CE3X of EFINOVATIC and CENER [12] at national level.
Finally, Zabalza et al. [13] study the evolution of building energy codes in Spain and their impact on residential thermal demand based on energy simulation. In their study, they include cities from five different climatic zones (Almería, Valencia, Santander, Zaragoza and Burgos) and to define the parameters related to buildings from periods after 1979 they take the values of the Basic Building Standard NBE-CT-79 about buildings thermal conditions [14] and the different versions of the Technical Building Code (CTE) Basic Energy Saving Document (DB-HE) [15]–[17].

1.2.Parameters for defining the energy performance of Building Clusters.

The previously mentioned studies define geometrical and/or thermal parameters that are of special relevance for characterising the building stock and defining the energy performance of its buildings. As a summary, table 1 collects the parameters that determine each of the reference studies and all the detailed information is included

Study	Scope	Window area	U values	Glazing g factor	Ventilation losses	Infiltration losses	Internal gains
Martín Consuegra et al.[2]	Madrid	X	X	X	X	X	X
Yang et al.[3]	Netherlands	X				X	
Rodriguez Lorite [9]	Alcalá de Henares Almería Jaén Donostia Tarragona	X					
Kurtz et al. [7]	Zaragoza	X	X				
Zabalza et al. [13]	Almería Valencia Santander Zaragoza Burgos	X	X		X	X	
TABULA [10]	13 european countries	X	X	X		X	
ENTRANZE [11]	European countries		X				
Fernández Luzuriaga [4]	Bilbao		X			X	
EFINOVATIC y CENER [12]	Climate zones CTE		X	X			
Oteiza et al. [6]	Madrid	*	X	*	*	*	*
Prades Gil et al. [5]	Valencia					X	
Calama-González et al. [8]	South Spain					X	

(*) It is unknown if they specify the indicated parameters since there has not been access to the study. The values for the U parameter are known through the study by Martín Consuegra et al.[2] that present the values proposed by Oteiza et al. [6].

1.2.1.Window area

In the estimation of window-to-wall ratio at urban scale the studies analysed propose different methods: taking the values of the TABULA project [3] as a reference, analysing samples [2], [7] , [9] or automating the obtaining of the geometry [18]. The values vary between 10 and 50%.

1.2.2.South equivalent surface (SES)

South equivalent surface (SES) introduced by Catalina et al. [19] measures the effect of solar gains by representing in a single parameter the glazed surfaces by orientation. To define it, the sum of the multiplication of the area of the glazed surface by the coefficient of its orientation has to be calculated. The coefficients determine the percentage of solar incidence on a vertical surface facing other than south compared to that which it would receive if it were facing south.

1.2.3.U Values

The transmittance of building elements is related to the year of construction or renovation of the buildings. To define the values belonging to buildings built in Spain in the period 40-80, it is not necessary to differentiate them by region of application, since the constructive solutions of that period are homogeneous for Spanish cities with housing built on a massive scale in the peripheries under functional urbanism models, due to the specific regulations for social housing and the lack of industrialisation of construction, which led to standard solutions [9]. Moreover, some authors agree that there are no decisive differences between social housing and free housing [20].
The assignment of U-values corresponding to each element of a building envelope according to its construction period is done under different criteria: the analysis of samples of the city of application [2] [6] [6] [7] or following the building energy codes corresponding to each climatic zone [13].

1.2.4.Solar g factor

The studies consulted that refer to the solar g factor of glazing [2] [10] [12] set the value between 0.65 and 0.82, while the regulation considers a value of 0.85 for standard single glazing and 0.75 for insulating double glazing and standard double glazed windows [21].

1.2.5.Ventilation losses and internal gains

Ventilation is one of the most difficult parameters to estimate as it depends on the behaviour of people using dwellings. There is no homogeneity in the classification of the ventilation rate according to the building construction period, use and location [22]. Likewise, infiltration losses are a complicate to estimate on a large scale since they depend on the airtightness of the building envelope, which varies depending on its state of conservation.
Martín Consuegra et al. [2] refer to the ISO 13790 standard for defining total ventilation losses, which proposes a minimum standard ventilation flow rate of 0.3 ACH. For dwellings without a forced ventilation system, the values depend on the number of exposed facades (one or more than one), the level of wind exposure of the building (no exposure, moderate, high) and the airtightness (low, medium, high). For moderate exposure, the values range from 0.5 to 0.9 ACH. In the case of Spanish regulations, the LIDER-CALENER Unified Tool (HULC) (CTE 2017) proposes a default value of 0.63 ACH for residential buildings.
Regarding ventilation losses, Zabalza et al. [13] define them in relation to the year of construction of the building and its building typology. From June to September from 01:00 to 08:59, they consider that the windows will be open, which corresponds to 4 ACH. During the rest of the year, they are defined according to the year of construction and the building typology. They are based on the updates of the Basic Document on Health and Safety of the CTE and for periods prior to 1979 they assume the default value of 0.63 ACH due to the fact that there was still no specific regulation in relation to air renewal.
The studies analysed assign the infiltration rate under different criteria: determining the air change rate by infiltration according to the building classification and year of construction defined in TABULA [3] [5], assuming the infiltration rate value defined by the Andalusian Housing and Rehabilitation Agency (AVRA) [8], taking as a reference the results of the Blower Door tests [4] or based on the doctoral thesis of Rodríguez Trejo [23] [13]. The values vary between 0.10 and 1.00 ACH.
Finally, to define the internal gains Martín Consuegra et al. [2] take the value estimated in ANNEX K.2 (UNE EN ISO 13790 : 2011 | ENERGY PERFORMANCE OF BUILDINGS - CALCULATION OF ENERGY USE FOR SPACE HEATING AND COOLING (ISO 13790:2008), 2008) for the internal gains in continuously occupied buildings of 4 W/m2.

2.METHODOLOGY

A methodology has been developed to characterise geometrically and thermally the building stock at urban scale in a systematised way through open data using QGIS. The parameters to be defined are; a) roof, façade and opening surfaces by orientation; b) U-values of the elements; c) solar g factor of the glazing; d) air renovations by ventilation and infiltration and e) internal gains. Some of the values for specifying the parameters are obtained by processing open data and others are estimated from the findings of literature reviews.
While defining the geometrical and thermal characteristics of the buildings, the project has assumed the following limitations:

-Buildings are not categorised by building typology.
-Unconditioned areas of the buildings are disregarded.
-The calculation of the façade surfaces is simplified; if there are projections on the horizontal plane, they are not taken into account.
-The same percentage of openings is defined for all orientations facades.
-For the definition of ventilation losses, it is assumed that ventilation is the same in summer as in winter and at night as during the day.
-Internal gains are considered to be continuous.

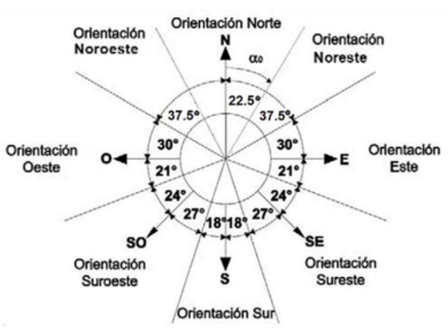
2.1. Geometric characterisation

The geometric characterisation is carried out by processing open data from the land parcels in shape format of the cadastres, which stores the geometric information of the elements of each municipality. In order to define the window-to-wall ratio, an analysis of seventeen representative buildings selected by construction period and number of floors distributed in different districts is also carried out. From the data obtained on building envelope surfaces and orientations, the general thermal conductance (UA) and the south equivalent surface (SES) are calculated.

2.1.1. Roof and façade surfaces by orientation

This methodology aims to consider only those parts of the envelope that delimit the spaces intended for residential use. The geometry of the buildings with residential use is defined from the treatment of the union of the layers ‘Element’ and ‘Common Element’, through which the roof surface is directly known. To define the length and orientation of the facades, the geometry is transformed from polygon to lines. From the façade lines, the angles of the façade normal that define the orientations according to the façade angles proposed by the Supporting Document to the Basic Document DB-HE Energy Saving of the CTE [24] are known, as shown in Figure 1.

Figure 1. Façade orientations CTE DB-HE Energy Saving, 2022 [24].



Norte	$\alpha_0 < 22,5$; $\alpha_0 \geq 337,5$;
Noreste	$22,5 \leq \alpha_0 < 60$
Este	$60 \leq \alpha_0 < 111$
Sureste	$111 \leq \alpha_0 < 162$
Sur	$162 \leq \alpha_0 < 198$
Suroeste	$198 \leq \alpha_0 < 249$
Oeste	$249 \leq \alpha_0 < 300$
Noroeste	$300 \leq \alpha_0 < 337,5$

To define the heights of the façades related to residential use, the number of floors with residential use are counted and multiplied by a height of 4m for ground floors and of 3m for upper floors. To validate the building heights, Digital Building Surface Models (DSM) are used which rasterise the relative heights of the building with respect to ground level with a grid pitch of 2.5 metres. There is the limitation that the data in the DSMs are not updated periodically and for some buildings there is no height data or if there is it does not correspond to the actual building.
Once the heights of the façades with residential use have been defined, the surfaces of the party walls and the façade surfaces in contact with outside air are differentiated. They are classified by the adjacency between the façade lines: when there are two adjacent lines (adjacency 2) it is considered to be a party wall and when there is only one line (adjacency 1) it is a façade in contact with outside air. In order to know the façade height in contact with outside air of two adjacent lines, their maximum and minimum heights are extracted. The maximum height (the height of the tallest building) is the external height of the façade and the minimum height (the height of the lowest adjacent building) is the internal height of the façade, which corresponds to the party wall. By subtracting the exterior height minus the interior height, the façade height in contact with outside air is obtained.
Finally, to determine the façade area per orientation of each building, the height in contact with outside air for residential use of the building is multiplied by the length of the façade.

2.1.2. Window surfaces by orientation. Window to wall ratio.

The percentage of façade openings is related to the period, building typology and climatology of the region. In order to define the window surface area by orientation of buildings on an urban scale, a window-to-wall ratio coefficient is applied which defines the percentage of openings in relation to the total façade surface area.
To establish these percentages, the values and methods of other authors are analysed and a detailed study of a small sample of the region analysed is carried out in order to contrast the percentages of façade openings of the references with real data. Representative buildings are analysed by period of construction, number of floors and district. In order to analyze the façades of the buildings studied, photographs of the façades are obtained using 'Google Maps' to make a detailed survey in AutoCAD that supplies measurements and window-to-wall ratio.

2.2 Thermal characterisation

After reviewing the literature and the regulation in force in each construction period regarding aspects related to the energy performance of buildings, the parameters that influence the thermal performance of the buildings are determined.

2.2.1. Thermal transmittance, U-values of elements: roofs, façades and windows

The construction periods are defined according to milestones in the use of new construction techniques and changes in the applicable regulations in relation to the energy performance of buildings. Seven construction periods are distinguished: 1900-1939 (A), 1940-1959 (B), 1960-1979 (C), 1980-2005 (D), 2006-2012 (E), 2013-2018 (F) and 2019-2023 (G).
The first three periods are those classified by TABULA according to changes in the use of new construction techniques. The period 1980-2005 is marked by the entry into force of the first regulation requiring energy efficiency conditions in buildings, NBE-CT79 1979 [15], whereby thermal insulation begins to be installed. The last three periods are set because in 2006 the CTE 2006 [16] comes into force and in 2013 and 2019 there are modifications [17] [18] that affect the requirements related to the thermal transmittance of the building envelope elements.

The U-values assigned to the first three periods are those proposed by the TABULA-EPISCOPE project [10], which refer to the most widely used building systems in Spain by period. With the exception of the transmittance of the windows, since in many cases the owners of the dwellings will have modified these elements in a non-uniform way in the whole building. This value is therefore set according to the criterion established by Oteiza et al. [6] in which a prorating of original windows, replacements and double windows is taken into account for which it is estimated that most of the frames are metal.
For the period 1980-2005 (D) the value proposed by the regulation (NBE-CT-79) is fixed and in brackets the average of the values obtained in the Fernandez tests is given for the walls and for the roofs and windows those proposed by Stegnar for TABULA.
In the case of the period 2006-2012 (E), the limit values corresponding to a building that will limit the maximum energy demand of the building (from table 2.2 of the CTE 2016) are given. In brackets the maximum thermal transmittance values per element are given (obtained from table 2.1 of the CTE 2016).
For the periods 2013-2018 (F) and 2019-2023 (G), the values of the regulation in force in each period (CTE-DB-HE-2013 and 2019) are given. In brackets the values proposed by EFINOVATIC and CENER [12] for the IDAE's CE3X Manual of Technical Fundamentals of Energy Rating of Existing Buildings are given. In a summary, in table 2 the U-values set for the project are grouped.

Table 2. U-values per period proposed for the project

Period	Scope	U wall	U roof	U window
A 1900-1939	State	2,63	3,38	3,90
B 1940-1959	State	2,53	2,65	3,90
C 1960-1980	State	1,43	2,27	3,90
D 1981-2005 NBE-CT-79	Climatic zone V and W Bizkaia, Gipuzkoa	1,80	1,40	3,70
	X	1,60	1,20	
	Y Araba	1,40	0,90	
	Z	1,40	0,70	
E 2006-2012 CTE 2006	Climate zone A	0,94 (1,22)	0,50 (0,65)	(5,70)
	B	0,82 (1,07)	0,45 (0,59)	(5,70)
	C Bizkaia	0,73 (0,95)	0,41 (0,53)	3,59 (4,40)
	D	0,66 (0,86)	0,38 (0,49)	(3,50)
	E	0,57 (0,74)	0,35 (0,46)	(3,10)

F 2013-2018	Climate zone α	1,35 (0,94)	1,20 (0,50)	5,70
CTE 2013	A	1,25 (0,50)	0,80 (0,47)	5,70
	B	1,00 (0,38)	0,65 (0,33)	4,20
	C Bizkaia	0,75 (0,29)	0,50 (0,23)	3,10
	D	0,60 (0,27)	0,40 (0,22)	2,70
	E	0,55 (0,25)	0,35 (0,19)	2,50
G 2019-2023	Climatic zone α	0,80 (0,94)	0,55 (0,50)	3,20
CTE 2019	A	0,70 (0,50)	0,50 (0,47)	2,70
	B	0,56 (0,38)	0,44 (0,33)	2,30
	C Bizkaia	0,49 (0,29)	0,40 (0,23)	2,10
	D	0,41 (0,27)	0,35 (0,22)	1,80
	E	0,37 (0,25)	0,33 (0,19)	1,80

2.2.2. Transmittance of the window to solar energy, glazing g-factor

In relation to the criterion used to define the thermal transmittance of the openings, an average value is defined of those relating to the original glazing considered as single glazing (0.85), those replaced by single glazing (0.85), those replaced by insulating double-glazing (0.75) and double windows (0.75). The solar g factor is therefore set at 0,80.

2.2.3. Ventilation losses and internal gains

Ventilation losses are set at 0.45 ACH without differentiating between season and construction period and infiltration losses at 0.60 ACH for buildings before 1979 and 0.40 ACH for buildings after 1979, approximating the criteria of Rodríguez Trejo [23]. For post-1979 buildings, it is increased from 0.30 to 0.40 ACH due to the high results of the Blower Door tests performed by the University of the Basque Country (UPV-EHU) presented by Fernández et al [25].
Finally, the internal gains are set at 4 W/m2 according to ISO 13790:2011 [25].

3. CASE STUDY

In order to explore the implementation of the proposed methodology, it is applied on buildings containing at least one dwelling in the city of Bilbao. The region analysed is located in the North of the Iberian Peninsula and is divided into eight districts: Deusto, Uribarri, Otxarkoaga-Txurdinaga, Begoña, Casco Viejo Ibaiondo, Abando, Rekalde and Basurto Zorrotza.
The district of Casco Viejo Ibaiondo is the oldest in the city, where the town was founded in 1300 with the Seven Streets. Between the 16th and 18th centuries the city developed and the population increased and the city extended to the other side of the estuary. At the end of the 19th century, the first widening project was approved, which was extended throughout the 20th century. At the same time, low-density buildings were constructed in the neighbourhoods on the slopes of the mountains, located in the districts of Deusto, Uribarri and Rekalde, and in the Otxarkoaga-Txurdinaga district in the 1960s the Otxarkoaga Supervised Settlement was built. At the end of the 1990s, a large-scale urban regeneration and renovation process began throughout the city.

3.1. Data source

Different public databases have been used to study the region. The cartography of the districts is obtained from Open Data Euskadi (EUSTAT, Basque Statistics Institute, 2022). The boundaries of the municipality and building information are obtained from the Cadastre of Bizkaia (Provincial Council of Bizkaia, 2023).

The Cadastre of Bizkaia provides cadastral cartography of the municipality's land parcels in vector format (shapefile - shp-). From this source of information, the use of the element and of the building, the floor number of the common element, the number of floors above ground level of the building and the year of construction and renovation are obtained directly. By processing the data, the number of total housing elements and per building and the number of floors with housing use per building are obtained. To validate the height of the buildings, the Digital Building Surface Models - MDSnE2,5 of the National Centre for Geographic Information (CNIG) (2010, 2012) have also been consulted. The information obtained is processed using QGIS.

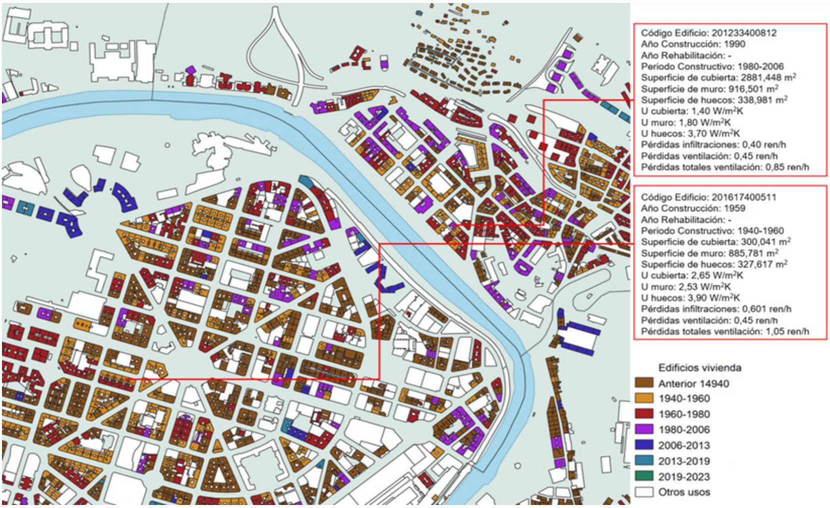
3.2. Validation

To validate the results obtained in QGIS, the values presented in the energy certificates of two buildings from the analysed region will be taken as a reference.

4. RESULTS

The city of Bilbao on the basis of the cadastral data of 2 June 2023 has 169.340 dwellings distributed in 10.805 residential buildings compared to the 162.672 registered by the INE census in 2011.
To define the window-to-wall ratio, an analysis of the representative buildings is carried out following the classification criteria by construction period and building typology of Fernández [4], which consists of identifying the most representative groups of dwellings, taking into account the weight of each group with respect to the residential stock. It considers as representative those groups of dwellings that have a weight greater than 2% of the total built-up stock. Depending on the year of construction, they are grouped into the following five stages: before 1939, from 1940 to 1959, from 1960 to 1980, from 1981 to 2005 and from 2006 to 2023. In terms of building typologies, buildings of 4 to 6 storeys and 7 to 9 storeys are considered representative for the first two construction periods and 4 to 6, 7 to 9 and more than 10 storeys for the later periods. The choice of the location of the buildings is made in such a way that the eight districts of Bilbao are represented. The values obtained for façade openings are between 9.49% and 41.19%. By calculating the average value, it is proposed to define the percentage of façade openings as 27%, which is close to the value used in other studies [9].
By applying the methodology to the region to be analysed in QGIS, data are obtained for each of the buildings on the year of construction and renovation, their construction period, the surface area of the envelope elements by orientation and their U value and, in the case of openings, the g factor and ventilation losses.
Figure 2 shows the categorisation of residential buildings according to the construction period of an area of Abando and Uribarri and two examples of the geometric and thermal characteristics obtained for each building.
Among the steps to be followed to process the cadastre data for the entire city of Bilbao in QGIS, long processes are identified (lasting more than 60 hours with a 12th Gen Intel® Core™ i7-1265U 2.69GHz processor and 16GB RAM) especially in obtaining the heights of the façade lines by orientation, due to the large number of elements to be analysed.

Figure 2. Geometric and thermal characterisation of large-scale buildings catalogued by construction period.



To validate the methodology, two buildings located in Bilbao for which we have energy certificates were chosen and the geometric data, the U and the solar factor obtained in QGIS were compared with the data presented in the energy certificates. As can be seen in figure 3, the first building is located in Deusto, opposite the artificial island of Zorrozaurre (at Av. Zarandoa, 17) and the second in Basurto Zorroza (at Estrada Entrambasaguas, 15 and 16). Both blocks were built in compliance with the CTE HE 2013 regulations. Figure 4 shows a view of each building and a comparative table of the values obtained in QGIS with those provided by the energy certificates.

Figure 3. Location of the validation buildings.

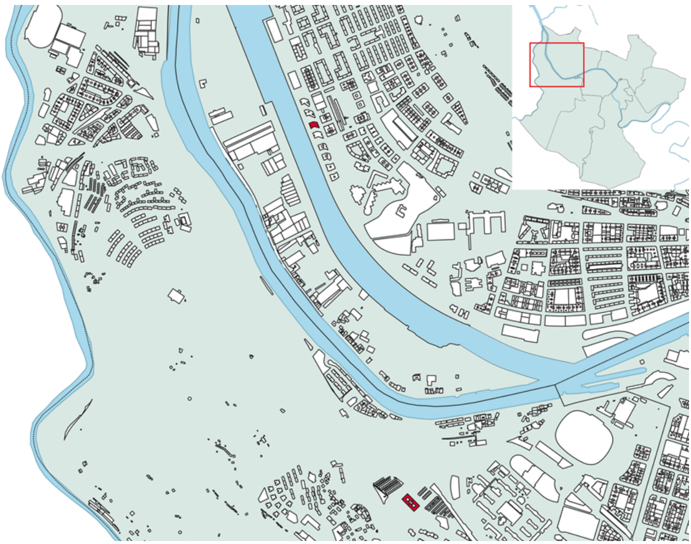


Figure 4. Values obtained in QGIS for the validation buildings and values of the energy certificates.

Edificio	Fuente	Superficie muro (m^2)	U del muro	Superficie huecos (m^2)	U de los huecos	Factor solar	Superficie cubierta (m^2)	U de la cubierta
104 VPT Zorrozaurre	QGIS	2201,30	0,49	814,18	2,10	0,80	660,155	0,40
	EPC	3344,46	0,29	642,96	1,66-1,68	0,45-0,56	588,32	0,22
78 VPO Basurto	QGIS	3627,08	0,49	1341,582	2,10	0,80	1728,814	0,40
	EPC	4790,71	0,29	1090,14	1,63	0,42	2588	0,36

Top left view of the Zorrozaurre building and top right of the Basurto building. Below, table comparing the geometric and thermal characteristics of the values obtained in QGIS with those of the energy certificates.

It's clear that the envelope surfaces obtained by QGIS are lower than those presented in the energy certificates, except in the case of the surface area of openings, which is 23-26.6% higher in QGIS than in the energy certificates.

It should be noted that this study is interested in knowing the surfaces linked to the use of housing, so surfaces linked to floors where there are no dwellings are not counted. Subtracting the percentage of façade area relating to the ground floor from the areas recorded in the certificates gives an error of 3.3-14.3%.

The same applies to the calculation of roof areas, whereby the areas in the energy certificates are adjusted to the areas related to residential use, resulting in an error of 12.1-18.5%.

Regarding the area of openings in the façade, it is worth considering the possibility of lowering the percentage of openings from 27% to 21% in order to adjust the values of the energy certificates more closely.

As for the thermal values, it can be seen that those of the energy certificates are lower than those proposed in this study, which comply with current energy saving regulations. An analysis of the values of the representative buildings of the city of Bilbao could be carried out to adjust the values proposed by the study, but this is ruled out as it would mean redoing the study for each region analysed.

5.CONCLUSIONS

This work proposes a systematised methodology to characterise geometrically and thermally buildings at urban scale from open data. It has been applied to the characterisation of the building stock of the city of Bilbao, located in the North of the Iberian Peninsula. The public data used are updated monthly, so that in cases where renovations are carried out, the values of the defined parameters would vary. The application of the methodology to the case study allows us to know the roof, façade and façade openings surfaces by orientation linked to the residential use of the buildings, the U-values of the envelope elements, the ventilation losses and the internal gains of each of the buildings in the city of Bilbao. The validation of two of the buildings in the case study showed an error of 23-26.6% in obtaining the surface area of the openings in the façade, 12.1-18.15% in the roof surfaces and 3.3-14.3% in the façade surfaces. The U-values of the building elements presented in the energy certificates are also lower than those proposed by the study due to the fact that the limit values of the standard are set. In future work, a sampling of the building stock could be carried out in order to define the most appropriate U-values.

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Study of an underground cistern as a thermal storage with HVACR system via heat pump assisted by PV: the case of the IWER building in Pamplona

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Key Words: Thermal Storage, PV, heat pump, thermal load displacement, load control

0.ABSTRACT

Given the global uncertainty surrounding energy prices and the urgent need to improve energy efficiency in the building sector, sustainable rehabilitation is becoming increasingly important. This is particularly true in the case of Spain, where the building sector is largely outdated. In response to this challenge, the OpenLab European project aims to refurbish the IWER building, a tertiary building located in Pamplona. The proposed HVACR system will be based on heat pumps supported by a large photovoltaic installation and contemplates a singular feature: an existing underground water cistern that can be used as a thermal storage. The use of such storage system can help compensate the inherent lack of flexibility in the energy consumption patterns of buildings in the tertiary sector.
The study involves a real-case simulation of a sustainable rehabilitation project, which expands previous general-case studies of solar assisted heat pumps with thermal storage for smaller, primarily residential buildings. To achieve that objective, simulations are performed by the Design Builder software using hourly data analysis. Different sizing and control strategies will be applied to meet the specific needs of the involved tertiary building. The results of the study show three main benefits: a reduction of the total HVACR installed power by using the thermal storage for peak shaving; an improved control of the HVACR production by decoupling production and demand while stabilizing the regime of the heat pumps, and, finally, a maximized photovoltaic self-consumption coupled with a shift of the electricity load to cheaper and more sustainable electricity consumption hours.

1. INTRODUCTION

Global warming is one of the most important scientific, engineering and social issues of this century. One of the many ways to fight against is energy efficiency, the reduction of energy expenditure through a better and optimized use of energy [1]. In this context, buildings are consumers of 40% of energy in Europe and 36% of greenhouse gas emissions [2], within which buildings destined to the tertiary sector in Spain are responsible for about 40% of building consumption [3]. In response, the use of renewable energy as well as more efficient technologies such as heat pumps have been widely applied in both the tertiary and residential sectors and have promoted their electrification [4]. This increased electrification has led to a rise in energy storage technologies: batteries, thermal storage, etc., due to two different factors: an uncertainty about the price and environmental impact of the electricity consumed and a highly variable demand curve, driven by the dependence of HVACR systems on climatic conditions [5]. The residential sector has been analyzed in greater depth, for example by Li et al and Rinaldi et al [6,7], but research in the tertiary sector in relation to thermal storage is in a nascent state, with studies such as the one conducted by Ragoowansi et al [8] recently.
In this context, the oPEN Lab project was born, whose main objective is the improvement of existing buildings and districts in three neighborhoods in the European cities of Tartu, Pamplona and Genk. In this project, the rehabilitation of the IWER complex in Pamplona will be addressed. It includes among its original facilities a 560m3 useful volume cistern, whose use as a thermal storage system will be analyzed in this work. This will be linked to the premise that the HVACR installation of the building will be carried out using heat pumps and photovoltaic energy on the roof.

To understand the benefits of using a storage tank in a heat pump system, some details are explained below. If the heat pumps operate without a storage tank, the thermal load of the building has to be covered in real time, so the pumps must be sized to cover the peak load, even though in a large percentage of hours of the year they do not operate at full load but at partial load [9]. This phenomenon can be alleviated with a storage tank. The heat pump feeds the tank and the tank feeds the demand, so that the heat pump can be sized at a lower load and use the tank to supply peak shaving. Secondly, heat pumps can always operate at nominal load with a more stable on/off regime. There are studies in the literature on this phenomenon [6,10], where a reduction in the installed power of heat pumps was achieved through the use of thermal storage and also a regularization of their operation that resulted in operational benefits.

Another possible benefit of thermal storage is the shifting of the working hours of the heat pumps to those that are preferable, by means of control strategies. This is especially important in systems with photovoltaic production, as they often have surplus energy that cannot be stored otherwise and must be consumed as it is generated. This exploitation has been studied by Dannemand et al., Heinz & Rieberer and Sohani et al. [11-13], where lower grid power consumption was achieved in simulations performed for buildings in the residential sector. Among the various control strategies for this higher PV energy harvesting, the present work will be based on those followed by Heinz & Rieberer [11]. In that study they found that by shifting heat pump production to sunny hours and changing the storage temperature setpoints to "overcharge" during hours of excess PV, up to 4% grid energy savings could be achieved.

A different control strategy tested particularly in the residential sector through the use of batteries and also thermal storage is to adapt electricity consumption to the price of grid electricity, so as to encourage consumption in low price hours and avoid high price hours. This has been studied among others by Agyenim & Hewitt,, Palani et al. and Pardo et al. [14-16].

These thermal storage techniques and control strategies have been studied mainly in the residential sector, as presented in the review of heat pump and thermal storage systems for buildings by Osterman & Stritih [17]. In it, more than 40 studies on TES with heat pumps are analyzed, although only one of them has an installed power and storage tank size similar to the magnitudes of this study (560m3 and demand of the order of 1500kW). This mentioned study was conducted by Kim et al [18] for an office building in South Korea. However, no control strategies were studied as a function of PV or off-peak hours.

Thus, this paper aims to evaluate the benefits of thermal storage in the real case of the IWER complex. The main objective is to analyze whether the benefits found in the state of the art on the use of thermal storage in the residential sector would apply to the case study of the IWER complex using its subway cistern as storage tank. These potential benefits are:

-Reduction of installed power in pumps thanks to peak shaving through the energy stored in the tank.

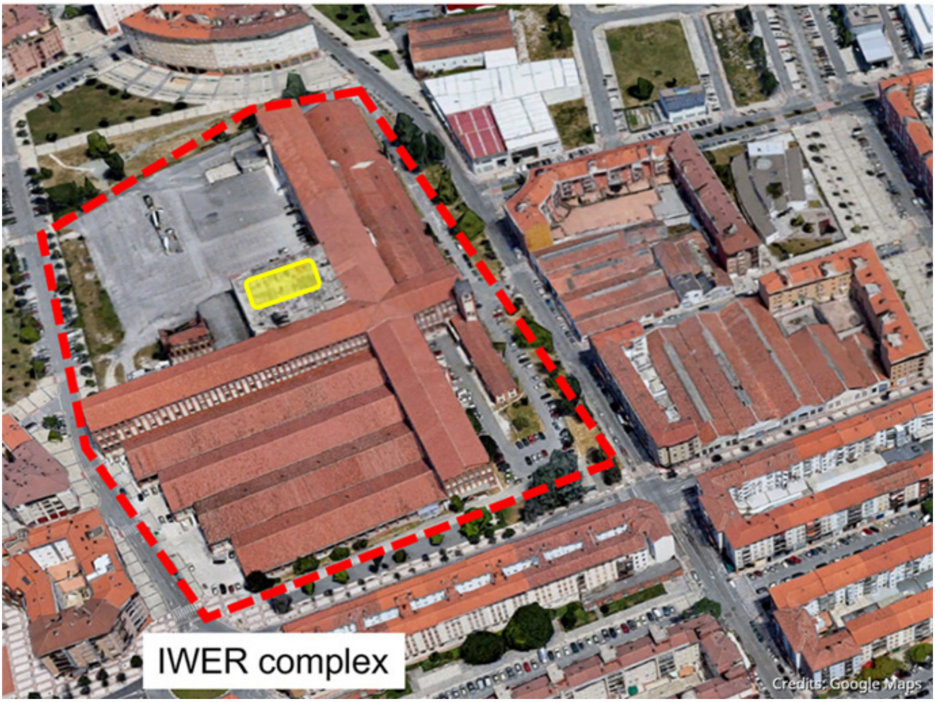
-Stabilization of the pump(s) regime, less starts and stops, more time at nominal load by partially decoupling demand from consumption.

-Energy and/or economic savings through the use of control strategies based on excess photovoltaic energy and electricity prices.

2. METHODOLOGY

Briefly introducing the IWER building, an aerial image of the building can be seen in Figure 1. This building is an old textile factory in the Rochapea neighborhood of Pamplona. The historical value and the good structural condition of the building has led to the consideration not of its demolition, but of its energetic rehabilitation with the aim of reviving the social climate of the neighborhood. Three of the four industrial buildings annexed to the building will be demolished to make room for a tree-lined square and the rest of the building will be maintained for different uses. The main use is offices on the middle and upper floors, but it will also have a gym, a supermarket, a nursing home, a loft complex and businesses open to the public on the first floor. This is the first interesting element for the thermal analysis of this building, its uses are diverse and so is the thermal demand curve, therefore requiring powerful thermal calculation tools for its analysis. The second reason for choosing this building for a thermal storage study is the presence of a subway cistern with a useful volume of 560m3. This cistern, marked in yellow in figure 1, being already present in the building does not require excavation and installation works, and only few studies have been carried out with water tanks already installed to evaluate a TES. This already existing subway cistern together with the variety of uses for the demand of the building gives rise to the interest of this particular case study, where techniques of using a TES usually studied in buildings of the residential sector will be evaluated and adapted to a high demand multipurpose building, mainly tertiary.

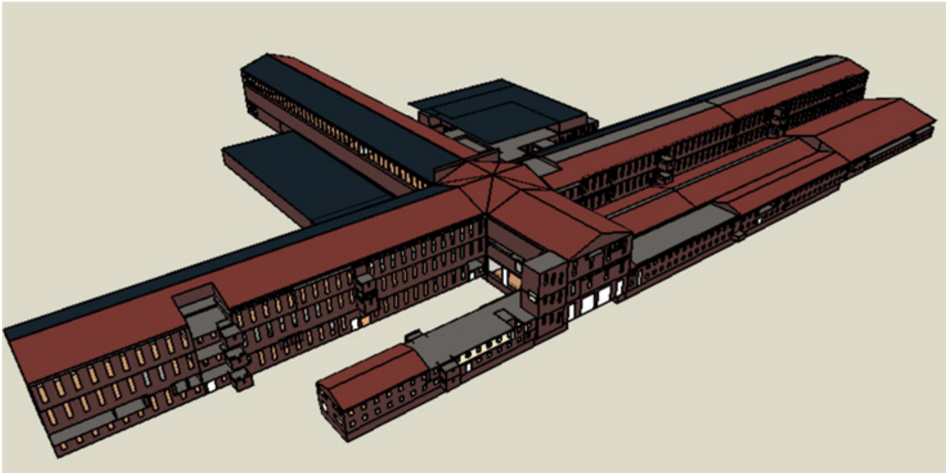
Fig.1: Aerial view of IWER complex and it's cistern.



First, a 3D CAD model of the IWER complex was imported from REVIT into Design Builder. After this partly automated import process with manual adjustments, the result is a geometric model of the IWER complex divided into zones according to their use, in total more than 50 zones. Secondly, a generic thermal envelope model was applied.

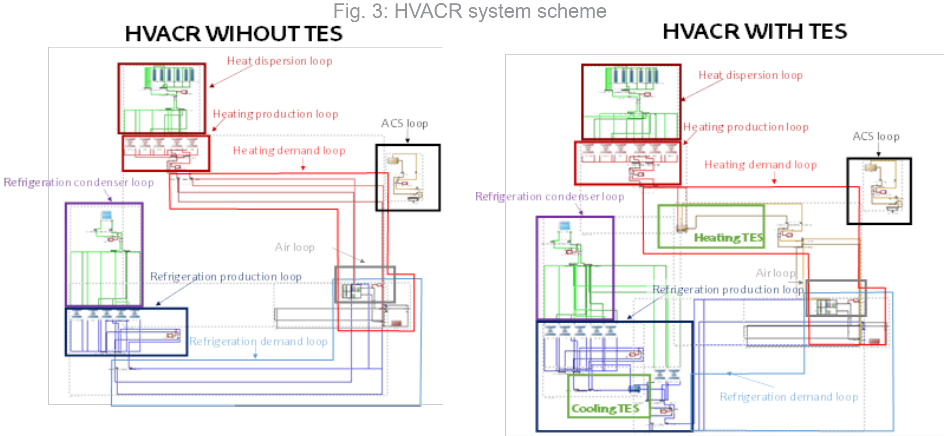
This study does not delve into the thermal envelope and therefore an existing envelope template in Design Builder called “Medium weight, moderate insulation” was used. Thirdly, an activity model was applied to each zone that reproduces a behavior faithful to the uses of each zone. For this purpose, both the basic DBHE document and the CTE were followed so that variables such as occupancy profiles, thermal power of equipment, lighting, etc., could be used. The rendered model of the IWER complex can be seen in Figure 2.

Fig. 2: Rendered model of the IWER complex in Design Builder



Finally, the HVACR systems without and with thermal storage were designed using the advanced HVAC module of Design Builder. The setpoint temperatures for cooling are 7ºC-12ºC and for heating 45ºC-40ºC, i.e. a thermal jump of 5ºC of the working fluid. To meet this need, water-to-water heat pumps were used, leaving Design Builder the job of auto-dimensioning as many variables as possible. Heat storage occurs between 50ºC and 45ºC, with overload up to 60ºC and cold storage occurs between 5ºC and 9ºC, with overload up to 2ºC. No heat losses have been modeled as this was a preliminary proof-of-concept study. The result of the HVACR system design in Design Builder following these assumptions is shown in Figure 3. In this model the heat pumps used are a model already introduced in Design Builder of a water-to-water heat pump with its operating curve introduced, and the number of heat pumps that satisfy the rated power adequately with the model used are between 4 and 5 heat pumps in parallel.

Fig. 3: HVACR system scheme



For the analysis, 3 weeks have been studied in each of the characteristic periods of the year. These periods are:

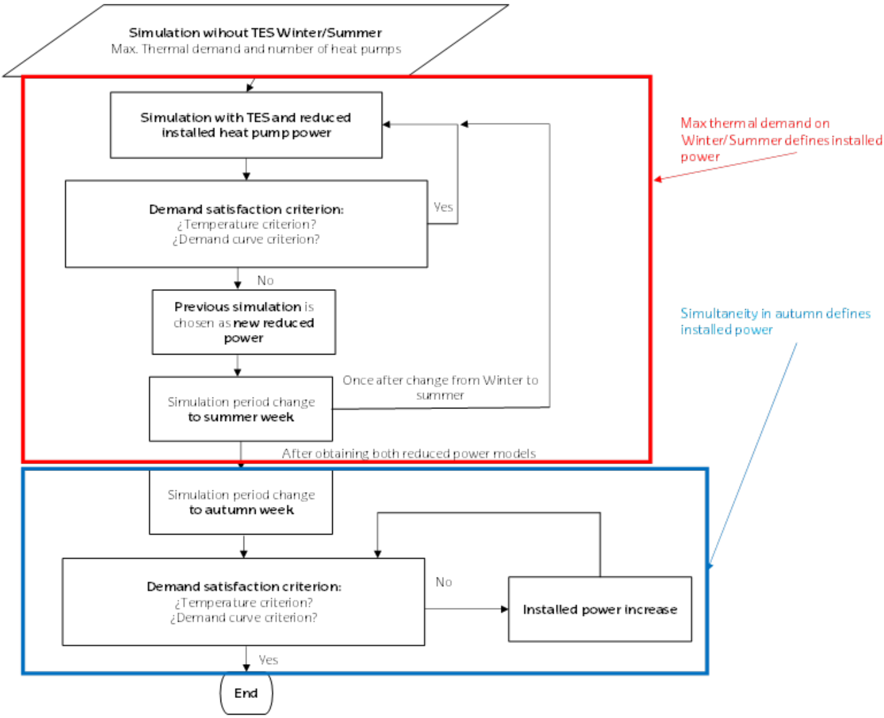
•Winter week (January 15 to 22). This period will determine the sizing of heating and will be used to analyze control strategies with low photovoltaic production, based on electricity prices.

•Summer week (July 8 to 15). This period will determine the sizing of cooling and will be used to analyze control strategies with high PV production, based on the use of excess production.

•Intermediate week (autumn): (October 7 to 14). This period will be used to determine the effect of simultaneous heating and cooling as well as to analyze mixed control strategies based on excess photovoltaic production and control based on electricity prices, all this in a period where the thermal load is not maximum.

The block diagram of the algorithm used to obtain the described models is shown in Figure 4.

Fig. 4: Block diagram of reduced power obtention algorithm



•Photovoltaic exploitation: On days when there is excess photovoltaic during the hours of excess all heat pumps are turned on to charge the TES up to its overload setpoint, and outside these hours only 1 heat pump can operate if and only if the TES reaches its discharge temperature.

•Electricity price-based control: Electricity free market prices in Spain were used to determine the highest and lowest price hours. These coincide with the “valley”, “flat” and “peak” hours of the Spanish PVPC price approximately. During the lowest price hours (valley) the tank is overcharged, during the intermediate hours (flat) the tank is charged but not overcharged and during the most expensive hours (peak) the heat pumps are deactivated except for one in case a slight compensation is necessary in order not to lower the temperature below the set point temperature.

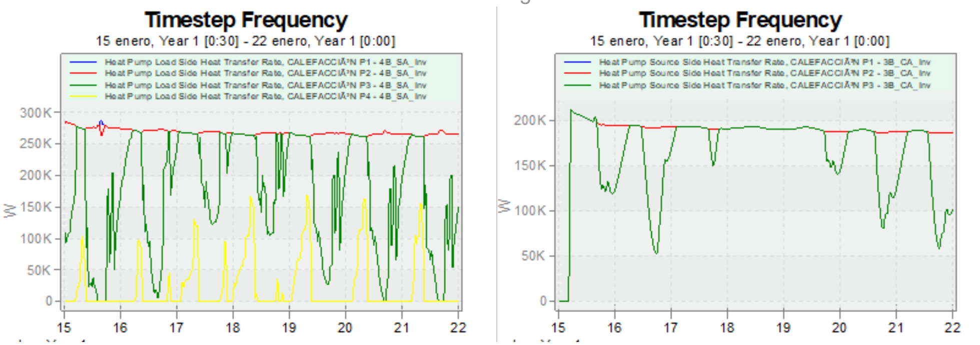
3. RESULTS

The first result is the reduction of installed power. The HVACR system with heat pumps without storage was sized to the minimum possible power, and then in the model with storage the power was further reduced until just before the thermal comfort conditions were no longer met. The resulting electrical power requirement for the heat pumps was:

- In winter: 960kW without storage and 788kW with storage; 18% reduction.
- In summer: 859kW without storage and 726kW with storage; 15% reduction.

The second result is the regularization of heat pump operation. Both in winter and in summer, the heat pump needed for consumption peaks, which used to operate many times off and at partial powers, manages to operate in a much more stable nominal power regime, reducing start-ups, shutdowns and their negative consequences.
This result can be clearly observed in figure 5, where the simulation in winter is shown. On the left can be seen the operation of the heat pumps during the winter week without TES, where up to 4 heat pumps are necessary to cover the demand in the peaks that occur early in the working morning. On the right-hand side you can see the model with thermal storage, where with just 3 heat pumps the demand was met. Looking at the curve on the left the first two heat pumps work 24 hours a day (red and blue curves overlap), but the 3rd and 4th only during peaks. The thermal storage causes the 3rd heat pump to operate more hours at rated power and these extra hours are used in peak shaving, reducing the maximum installed heat pump power necesity.

Fig. 5: Thermal power of heat pumps in winter week. On the left without storage and on the right with storage.



The third result is an improvement in energy efficiency through the use of control strategies. For different installed powers, the behavior of the system was simulated without storage, with storage and with storage and control strategies. This section summarizes the results of the simulations with 4 of the heat pumps used, representing the minimum power without storage.
Figure 6 presents the results, where the values of the simulations without thermal storage have been taken as 100%. The year of study is 2022, but the winter strategy by price-dependent control was also studied in 2023, marked by the superscript in the table.

The results show several phenomena:

- The thermal jump of the heat pumps increases due to the storage temperatures being higher in heating and lower in cooling in order to accumulate (Ex: The chilled water demand for cooling is at 7ºC but it accumulates even up to 2ºC). This causes a reduction of the COP of the heat pumps and an increase of their electrical consumption. This increase in consumption is a negative phenomenon that will affect the possible savings through control strategies.

•The savings strategy based on photovoltaic utilization has the best results. It shows positive results both in summer and autumn, causing a 7% reduction in grid energy consumption compared to the model without TES and control strategies.

•The control strategy as a function of the hourly price has positive effects, as it at least partly compensates the extra consumption caused by the higher thermal jump even in winter and leads to higher savings in autumn. The variation is large depending on the electricity price.

Fig. 6: Results using control strategies.

	WITH control strategies		
Electricity consumption	**Winter**	**Summer**	**Autumn**
	109%	93%	94%
Electricity cost	**Winter**	**Summer**	**Autumn**
	107% *2022 102% *2023	92%	92%

4. CONCLUSIONS

For the conclusions, his study has evaluated the benefits of thermal storage for the residential sector, for the real case of the IWER building, using as TES the subway cistern it has. The results obtained reproduce the benefits that we wanted to study with orders of magnitude very similar to those found in the literature. First, regarding the use of the TES for peak shaving, a reduction of installed power of 18%-15% was obtained, which, at the same time, stabilizes the operation of the heat pumps by reducing their partial load hours, as well as their on and off times. Second, we applied tested control strategies based on two variables: excess PV production and electricity price. The results show that both strategies improve the energy efficiency of the building compared to not using them and reduce the consumption of grid energy in the case of photovoltaics as well as the cost of grid electricity. However, in times of low PV production, grid consumption can be even higher, due to an increase in production resulting from a higher thermal jump in the heat pumps. Whether this consumption is higher or lower is highly dependent on the electricity price for the year in question. For future studies, it is recommended to perform a parametric study simulating in full years, instead of typical weeks. This should be done for several years, including future estimates of both climate and electricity prices and an automated programming of control strategies instead of manual ones. These results would be communicated into the work package of the HVACR in the refurbishing project and considered.

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Fluid dynamic based modelling approach for indoor air quality assesment in buildings

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Key Words: Indoor Air Quality, Buildings, CO_2 emissions, CFD, Energy efficiency

0.ABSTRACT

There is a conflict of interests between making an indoor space both energy efficient, and well ventilated. In a room that is effectively sealed or poorly ventilated, there is low energy consumption in air conditioning. Contaminants such as CO2 and airborne viruses remain and accumulate in the room, potentially causing health issues or exacerbating existing medical conditions. The increase of room ventilation will decrease the contaminant accumulation, but the energy consumption related to air conditioning systems will be increased. Therefore, an equilibrium between both is desirable.
In this work, the effectiveness of Computational Fluid Dynamic (CFD) is analyzed predicting the behavior of air and the diffusion of contaminants, CO2, in an indoor space. By ANSYS Fluent software a 3D modelling is carried out. Appropriate grid size (to provide reliable results from multiple locations) is determined based on room dimensions prior to running the modelling. This methodology provides data for the whole room, not just where the sensors are situated, as in the in-situ measuring method. The CFD modelling is based on the dimensions and layout of a dedicated test room located in KUBIK experimental building of Tecnalia. The CFD results are compared to experimental data obtained from standard measuring equipment used in the test room. The test room is equipped with CO2 exhaust ports to simulate the CO2 emissions emitted by plants and people. Additionally, there are strategically located sensors for recording CO2 levels.
If good agreement between modelling results and experimental data are obtained, the developed CFD model will be of interest at the design stage of new buildings to find the best solution that guarantees both air quality and energy efficiency

1. INTRODUCTION

According to the Unites States Environmental Protection Agency, people spend 90% of their time in interior spaces, so that ensuring that these spaces do not pose a risk to health is essential. Indoor Air Quality (IAQ) is directly related to it [1]. When air quality is poor, the concentration of pollutants can increase, exasperating negative health effects. During recent years, the drive to create more energy efficient buildings has led to the creation of buildings which are more air-tight, to the detriment of air quality and ventilation. For these reasons, such interiors have become a greater source of respiratory disease. These health effects are, in general, due to a high concentration of pollutants. Pollutants and their concentration can be diverse, depending on factors such as location, climate, ventilation method, presence of industries, etc. Whatever the reasons, indoor spaces must always ensure that the levels of pollutants do not affect people's well-being. To achieve this, ventilation strategies are essential, which allows clean air to be introduced and polluted air to be extracted. Ventilation systems are, by definition, mechanical systems created with the purpose of fulfilling the air renovation function and helping to improve IAQ.
Accordingly, ventilation systems must be designed to be as efficient as possible, ensuring adequate IAQ in the space at a reasonable cost. For this reason, accurately measuring IAQ is increasingly important. Today, the method used for this type of evaluation consists of measuring the concentrations of pollutants in actual interior space with sensors.

The objective of this work is to evaluate Computational Fluid Dynamic models (CFD) as an alternative method of evaluation, in particular, whether it is possible to study the diffusion of pollutants in indoor air, and how ventilation affects their movement. CFD models are simulations of actual spaces in which fluid dynamic equations are applied to study the movement of fluids. The application of this tool in this area may bring several benefits, such as evaluating IAQ from drawings, even prior to construction, saving time and material. Consequently, companies could implement these models in the design of new buildings, in order to optimize their ventilation design and costs.
To assess whether CFD modeling is suitable, a comparison between experimental data and modelling results is carried out. This was done using an experimental room of KUBIK research facility [2], which is fitted with a standard ventilation system. The contaminant under study in this work was CO2. Therefore, if modelling results and experimental data values match well, the viability of implementing CFD computing tools in IAQ studies is demonstrated.

2. EXPERIMENTAL INDOOR ROOM

The main objective of this work is to verify if the CFD tool is valid for the study of air movement and the diffusion of pollutants in indoor spaces. For this, an experiment has been carried out in one of the KUBIK's experimental rooms, and the experimental data have been compared with the CFD modeling results of the same room. KUBIK is a building designed by Tecnalia with the purpose of carrying out experiments under real and different environmental conditions. The room that has been studied in this work is located on the first floor of this building and has an area of 48.72 m2 and a height of 2.97 m.For this work, the test that has been carried out consists of the emissions of CO2 with the mechanical ventilation system activated. Then, the CO2 concentrations have been measured at different points, using the installed sensors. Taking into account the flow rates, dimensions and temperatures during the experiment, later the CFD model has been created. Therefore, the equipment installed and used in the experimental room for the test are.

-The CO2 injection network: it is made up of different devices. On the one hand, there is a CO2 bottle. This bottle expels a flow of CO2 that is specified by means of a valve and it is strategically distributed throughout the room by expulsion tubes. These tubes have a diameter of 6 mm and emit the CO2 at ground level.

-Air impulsion system: There are 4 diffusers to introduce clean air into the room, 2 of them located on the ceiling, and 2 located on the floor. However, in this experiment only the 2 of them located on the ceiling have been used. The air blown into the room enters with a rotational movement, due to the geometry of the diffusers. To control the ventilation in the test room, there is a specific Monitor Control Unit (MCU) that allows controlling the air intake flow in the test space.

-Extraction system: for the extraction of contaminated air, and to ensure the renewal of indoor air, an extraction system is available. In this room, one lineal extractor is installed for renovation purposes.

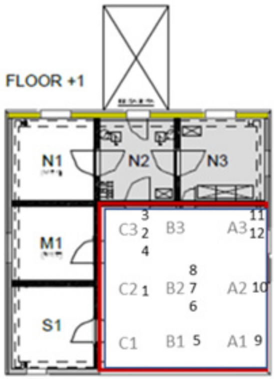
-Measurement network: In order to make the measurements, there are sensors that measure the concentration of CO2, temperature, relative humidity and pressure in the place where they are installed. There are 12 probes with the same characteristics, numbered 1 to 12 respectively. In Table 1 and Fig. 1 sensors distribution is shown.

Table 1 sensor distribution. Distribución de los sensores

sensor nº	Cell position	Height [cm]
1	C2	110
2	C3	110
3	C3	170
4	C3	10
5	B1	110

6	B2	20
7	B2	110
8	B2	170
9	A1	110
10	A2	110
11	A3	170
12	A3	110

Fig. 1 sensor distribution. The room used in the tests is marked in red.



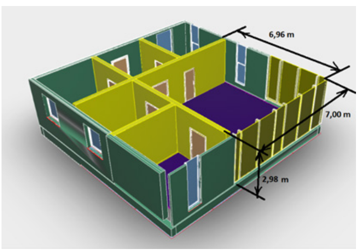
3. NUMERICAL SET UP

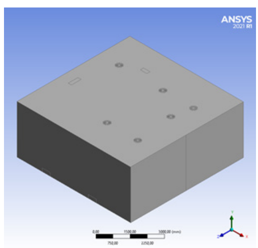
To made KUBIK room modelling, the software that has been used is ANSYS Fluent. To create the model, the workflow followed is: first the 3D geometry, second mesh, third define boundary conditions and physical models and last the postprocessor, results analysis.

3.1 GEOMETRY

The first step of the CFD modelling is to generate the 3D geometry of the object. In this problem, this geometry is equivalent to the volume of the fluid, specifically, the volume that the air and CO2 take within the room. For this, the dimensions of the KUBIK room were measured, Fig. 2, and a replica of the room has been made in Fluent.

Fig. 2 a) plan of the experimental KUBIK room and b) 3D geometry in Fluent





3.2 MESHING

Both the type of mesh and its distribution or discretization are important steps in this type of simulation. Depending on these, a mesh can be more or less reliable, and can require more or less computing time. In order to reduce the computational cost, the mesh that allows reaching a reliable result with the least number of cells was chosen.

As for the type of mesh, polyhedral geometry is a type of mesh that has more number of nodes per cell than tetrahedral and hexahedral meshes. This allows the calculation time to be reduced up to 50%. The geometry of a room is easily divisible by means of polyhedral cells. For these reasons, the polyhedral mesh is the one that was chosen in this work.

On the other hand, an important factor is to evaluate how many cells are necessary to achieve the desired results. To optimize and find this “ideal” mesh size, the Grid Convergence Method (GCI method) is followed, published by the Fluids Engineering Division of ASME [3]. This is a guide that provides specific guidelines for calculating and reporting discretization error estimations in CFD simulations.

In this process, the results of one or some variables within the same problem are evaluated, and the results obtained for three different mesh sizes are compared. For this, the GCI uncertainty value due to discretization (also known as mesh convergence index) is calculated. In this work three mesh are compared; the mesh with the greatest number of elements (the finest or small) is called MESH 1, the intermediate mesh is MESH 2, and the mesh with the fewest cells (the coarsest or big) is called MESH 3. The equations used in this calculation are as follows:

$$h_i = Volumen\ total\ de\ la\ habitación\ \div\ Número\ de\ elementos_i \quad \text{Eq. 1}$$

$$r_{i,j} = {h_i}/{h_j} \quad \text{Eq. 2}$$

$$\varepsilon_{i,j} = \varphi_i - \varphi_j \quad \text{Eq. 3}$$

$$s = sgn\,(\varepsilon_{3.2}/\varepsilon_{2.1}) \quad \text{Eq. 4}$$

$$p = \frac{1}{\ln(r_{2.1})} \times \ln\left|\ln\left|{\varepsilon_{3.2}}/{\varepsilon_{2.1}}\right| + Q(p)\right| \quad \text{Eq. 5}$$

Eq. 1 represents cell size value, Eq. 2 refinement factor, Eq. 3 the calculation of the truncation error between a mesh and its finer mesh, Eq. 4 the calculation of the unit parameter and Eq. 5 calculation of the apparent order of convergence.

$$Q(p) = \ln\left(\frac{(r_{2.1}^p - s)}{(r_{3.2}^p - s)}\right) \quad \text{Eq. 6}$$

$$e_a^{i,j} = \left|\frac{\varphi_j - \varphi_i}{\varphi_j}\right| \quad \text{Eq. 7}$$

$$GCI_i^{i,j} = \frac{1{,}25 \times e_a^{i,j}}{r_{i,j}^p - 1} \quad \text{Eq. 8}$$

Eq. 6 calculates function q, Eq. 7 calculates the relative error and finally Eq. 8 calculates the GCI, degree of uncertainty due to discretization. The first step is to create the three meshes and compute a representative cell size value for each, called h, Eq. 1. The relationship between one mesh and the next finer mesh is called the refinement factor and is represented by the letter r, Eq. 2, see results in Table 2. In addition, an r-global value is calculated between the finest and coarsest mesh and which, according to the method, must be greater than 1.3, see results in Table 3.

Table 2 number of elements and representative cell size value of each mesh

		$Number\ of\ elements_i$	h_i (m)
MESH 1	SMALL	772.215	0,000188
MESH 2	IINTERMEDIATE	531.975	0,000273
MESH 3	BIG	345.732	0,000420

Table 3 values of the refinement factor

	$r_{i,j}$
$r_{2.1}$	1,45
$r_{3.2}$	1,54
r_{global}	2,23

For this calculation, only the movement of the fluid inside the room has been simulated. To do this, air inlets though diffusers located in the ceiling and the floor have been defined simultaneously as boundary conditions, and the exhaust air through extractor has been defined as outlet. In this simulation, the CO2 inputs have not yet been taken into account, since we only want to know if the mesh converge or not. To see if the meshes are adequate enough, the speed values obtained in the extractor have been observed, since it is an area of interest. The velocity for each mesh is represented by the symbol φ_i. Specifically, the following parameters are measured in the extractor: the average velocity, the maximum velocity, and the velocity at the center point. Subsequently, the values for the parameter ε are calculated, Eq. 3, which indicates the truncation error in the result of the variable between a mesh and the finer mesh. The unitary value of s is also calculated, Eq. 4.

Table 4 velocity values for the three meshes, truncation errors and parameter s

	MESH 1 ($\varphi_1\ m/s$)	MESH 2 ($\varphi_2\ m/s$)	MESH 3 ($\varphi_3\ m/s$)	$\varepsilon_{2,1}$	$\varepsilon_{3,2}$	s
Average velocity	0,392	0,391	0,392	-0,0014	0,0018	-1
Maximum velocity	0,421	0,415	0,417	-0,0058	0,0021	-1
Velocity at the center point	0,399	0,400	0,406	0,0010	0,0054	1

Then, it is proceed to calculate the apparent order of mesh convergence, represented with the letter p, Eq. 5, which depends on the function Q(p), Eq. 6. The apparent order of convergence indicates the speed with which the numerical computation converges.

Table 5 values of apparent order of mesh convergence, relative errors, and degree of uncertainty.

	$Q(p)$	p	$e_a^{2.1}$	$GCI_1^{2.1}$	$e_a^{3.2}$	$GCI_2^{3.2}$
Average velocity	-0,02	0,56	0,37%	1,99%	0,46%	2,50%
Maximum velocity	-0,14	3,19	1,39%	0,76%	0,50%	0,27%
Velocity at the center point	-0,28	3,79	0,25%	0,10%	1,34%	0,54%
Average GCI				0,76%		0,54%

According to the guide [3], the values of uncertainties (GCI values) accepted must be below 5%, and they are very good if they are below 2%. In the results, the maximum value obtained is 2.50% in MESH 2 and 1.99% in MESH 1. The average values are 0.54% in MESH 2 and 0.76% in MESH 1. This means that both mesh 2 and 1 are suitable for simulations. In this work, the mesh with the lowest computational cost has been chosen. This is mesh 2, which has a number of 531,975 cells. This is the mesh used to calculate the diffusion of CO2 within the room.

3.3 CONFIGURATION

Taking into account the experimental data during the test, the following boundary conditions are defined:

-Air inlet flow: due to the characteristics of the experimental installation, the ventilation flow (impulsion) was approximately 375 m3/h. On the other hand, it is considered that this air comes from outside. Therefore, its CO2 concentration is the same as in outdoor spaces. For this reason, a concentration of 450 ppm of CO2 is considered at the ventilation inlet. The air inlet temperature was 300 K.

-CO2 inlet flow: According to the information from the valve to dispense CO2, the measuring balloon indicates the volume of CO2 emitted by the bottle in cubic feet. For the tests, the CO2 emission valve was set at 1 ft3/h, which corresponds to 0.03 m3/h of CO2. The CO2 inlet temperature was 300 K.

-Outlet flow: The mixture of air and CO2 that comes out of the extractors is defined by the pressure at the outlet. This value is 101.325 Pa, which equals to atmospheric pressure.

The models used during the modelling are; the species transport model, which allows to take into account both components (air and CO2) and calculating the diffusion between them and their concentrations at all points, and SST k-ω model which behave adequately at high and low Reynolds numbers [4].

4. RESULTS

In this section the modelling results are shown for the MESH 2, where two roof diffusers emitting outside air to the room and one extractor extracting inside air are operating, with a flow of 375 m3/h are considered. The CO2 emission from the bottle is 0.03 m3/h. Developed 3D model allows observing the behavior of the gas throughout the entire room, identifying the most problematic areas, and calculating the CO2 mass fractions at any point of the geometry. The following images (Fig. 3, Fig. 4, Fig. 5, Fig. 6) show the distribution of the gas, when it is introduced under these conditions:

Fig. 3 volume rendering of CO2 mass fraction.

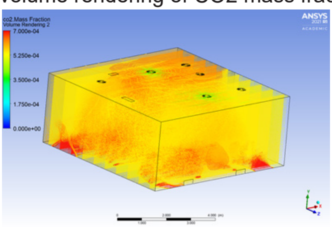


Fig. 4 streamline of CO2 mass fraction.

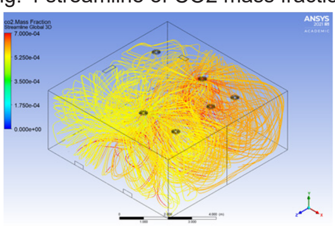


Fig. 5 streamline of CO2 mass fraction in the perpendicular planes to the inlet and outlet of the fluid.

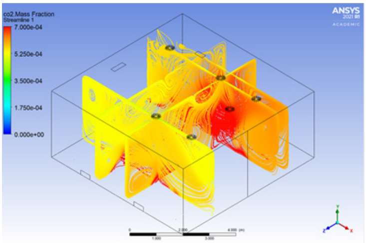
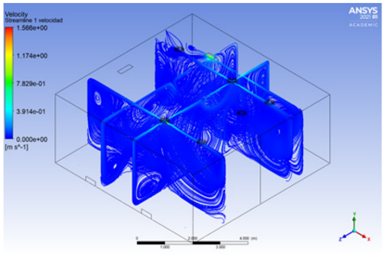


Fig. 6 streamline of velocity of the fluid in the perpendicular planes to the inlet and outlet of the fluid.



In the Fig. 3, Fig. 4 and Fig. 5 there can be appreciated red zones where the CO2 concentration is higher, close to the floor, see Fig 3. There, several red zones are appreciated, but the location agree well with the CO2 nozzles.To validate the CFD modelling results, the experimental measured CO2 concentrations at different positions are compared with modelling results. Therefore, the CO2 mass fractions calculated by the model for each position is used to calculate the CO2 ppm concentration following Eq. 9.

$$[CO_2]\, ppm = \frac{W_{CO_2}}{1 - W_{CO_2}} \times 10^6 \qquad \text{Eq. 9}$$

where W is mass fraction.

In order to validate the implementation of CFD models in this field, the results of the model were compared with the experimental results obtained in KUBIK. The CO2 concentrations in the tests were measured through the sensors. It is worth mentioning that during these tests an attempt was made to simulate stationary conditions. Therefore, the concentration of CO2 that will be used in the work is the equivalent to that achieved in equilibrium.

Table 6 shows the CO2 concentrations measured experimentally in KUBIK, the CDF modelling and the estimated error, calculated following Eq. 10. The total error calculated is the average of all of them.

$$Error = \frac{[CO_2]\, ppm\ measured\ in\ KUBIK - [CO_2]\, ppm\ measured\ with\ CFD}{[CO_2]\, ppm\ measured\ in\ KUBIK} \qquad \text{Eq. 10}$$

	Mass fraction CO_2	kg CO2/kg air	$[CO_2]$ ppm CFD	$[CO_2]$ ppm KUBIK	ERROR
sensor 1	0,00056	0,000558	558,31	587	5%
sensor 2	0,00056	0,000558	558,31	615	9%
sensor 3	0,00056	0,000562	562,32	615	9%
sensor 4	0,00057	0,000572	572,33	709	19%
sensor 5	0,00062	0,000620	620,38	617	-1%

sensor 6	0,00082	0,000824	823,68	582	-42%
sensor 7	0,00060	0,000603	603,36	595	-1%
sensor 8	0,00058	0,000575	575,33	579	1%
sensor 9	0,00053	0,000526	526,28	620	15%
sensor 10	0,00060	0,000595	595,35	657	9%
sensor 11	0,00061	0,000605	605,37	679	11%
sensor 12	0,00060	0,000602	602,36	794	24%

Comparing modelling results with experimental data in Table 6, it is appreciated that the differences are very small. Therefore, it can be concluded that the CFD modelling results agrees well with the experimental data, showing an acceptance performance of the CFD modelling results. The greatest difference is appreciated first, in sensor 6 and second in sensor 4. Both sensors are located close to the floor and close to the CO2 nozzles, 20 cm and 10 cm height respectively. One of the simplifications followed in this work was to suppose that the CO2 nozzles were at floor height, but in the experimental room, they are not in the same plane as the floor but somewhat elevated. Therefore, it can be concluded that the zones close to the CO2 nozzles are more sensible to changes when they are modelled by CFD.

5. CONCLUSIONS

In this work it has been observed that CFD models are a great tool in predicting the movement of CO2 pollutants in indoor spaces. It can be considered that the results obtained in the KUBIK room and those extracted from the model are quite similar. In this sense, the difference between them could be caused by various reasons, for example, equipment errors, few comparison points, equipment and model uncertainties, etc. Despite these errors, it can be said that these models are highly applicable in this area, and that, in addition, they imply several benefits compared to the traditional method of measurement with sensors.

One of the benefits of this tool is being able to predict the movement of the fluid. This makes it possible to estimate the critical points, and see if the new ventilation air is distributed correctly in the room. As it can be seen in the case of the KUBIK room, the distribution of CO2 is not homogeneous, and there are areas where the pollutant accumulates. This is an aspect to consider, since if the input CO2 concentrations were to increase, these points could easily exceed the limits established by the regulations. In this way, it can be seen that, as the gas accumulates locally, the installed ventilation system is not being fully effective. This information could be of great help in the future design of a new ventilation strategy.

Although this work focuses on a very specific situation, it can be concluded that the simplifications made in this work, the type of boundary conditions and physical models used in ANSYS Fluent are suitable for modelling in this area. Therefore, they could be applied in other geometries to study CO2 concentration and air movement

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The suitability of the TAIL Index in social housing of the Basque Country for the evaluation of the indoor environment quality

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Key Words: Indoor Air Quality, Indoor Environment Quality, TAIL Index, social housing

0.ABSTRACT

The TAIL Index is a comprehensive indicator to assess the Indoor Environment Quality of buildings (IEQ). It was first developed to assess the IEQ in tertiary buildings undergoing deep energy renovation. In this study, we apply this methodology in four dwellings of a social housing building in order to assess the suitability of this indicator in this type of buildings. The results show a comprehensive picture of the IEQ of the building which is not usually obtained with other indicators, and allow the renovation measures to be prioritized. Several advantages and disadvantages of the methodology have been identified. In the end, several suggestions towards the improvement of this indicator in social housing buildings are given.

1.INTRODUCTION

Regarding the outdoor air quality, it is already being widely analyzed by several organizations and initiatives, both at European and international levels [4], [5]. On the other hand, it is also common to find studies in the scientific community regarding the assessment of Indoor Air Quality (IAQ) [6]–[10]. Some studies focus on the development of complex modelling tools to evaluate the IEQ in buildings, based on holistic evaluation or calculation methodologies. Most works analyze the IEQ of buildings during the operational phase or following post-occupancy methodologies. In addition, many of the Green Building Certifications (GBC), such as BREEAM [11] or LEED [12], consider within their schemes the assessment of IEQ and prescribe their ranges to ensure that IEQ conditions in buildings are acceptable, with zero or low health risks and high occupant well-being [13]. Consequently, both the scientific literature and the GBC are a useful source for guidance when selecting parameters to assess the IEQ in buildings.
The ALDREN [14] project, developed from 2017 to 2020, aimed to overcome market barriers and promote the deep renovation of office buildings and hotels. Within this project, a comprehensive review of the parameters used in GBC for assessing the IEQ has been done [15], analyzing their relevance and accuracy. The main conclusion of this work is that all of the aforementioned scientific studies and GBC agree that IEQ consists of four major components: thermal environment, indoor air quality, acoustic environment, and visual environment. However, there is no common definition or agreed standard set of parameters that should be measured to characterize the IEQ and there is no standard IEQ metric.
Therefore, within the framework of the ALDREN project, a new classification rating scheme, the TAIL Index [16], [17], was developed to assess the IEQ in offices and hotels undergoing deep energy renovation. The TAIL Index assesses the Thermal Environment (T), the Acoustic Environment (A), the Indoor Air Quality (I) and the Visual Environment (L). The overall principle of TAIL is that it presents the quality of each of the components defining indoor environmental quality separately and then integrates them into one index describing the overall quality of the indoor environment, all shown as one label or tag. Twelve parameters are rated by measurements, modeling, and observation to provide the input to the overall rating of the IEQ. This is also one of the main strengths of the TAIL Index, that the majority of the parameters are measured; thus the results of the TAIL Index are based on real data.

The quality levels of the parameters are determined primarily using the Standard EN-16798-1 [18] and the World Health Organization (WHO) [19] air quality guidelines and are expressed by colors and Roman numerals to improve communication.
The TAIL Index has been proven over recent years to be a consistent and comprehensive methodology to assess the IEQ in tertiary buildings [20], [21]. However, the use of the TAIL Index to assess the IEQ in residential buildings has not been well developed. Evidently, several studies can be found among the literature regarding the assessment of IEQ in buildings [IEQ], but again the same lacks as identified in tertiary buildings are found. The intention of the TAIL Index is also to provide a proper reference that can be used broadly for any future research and development activities that require the IEQ rating in buildings. Recently, new recommendations have been provided by the ALDREN project to analyze residential buildings [22].
In this work, we analyze the viability of the TAIL index in social housing dwellings. Four dwellings of a social housing building of the Basque Country have been selected for the study. The IEQ of these dwellings have been assessed with the TAIL Index following the methodology described within the ALDREN project [16], [22]. Besides the results of the TAIL Index, a discussion regarding the viability, advantages, and disadvantages of this methodology to assess the IEQ in social housing buildings is developed.

2. METHODOLOGY

2.1 Description of the TAIL Index

As explained above, the TAIL Index was developed within the ALDREN project [16], [22] to analyze the IEQ in tertiary buildings. It assesses separately the Thermal Environment (T), the Acoustic Environment (A), the Indoor Air Quality (I) and the Visual Environment (L), and then integrates them into one single index describing the overall quality of the indoor environment.
The TAIL Index is derived from 12 different parameters rated by real in-situ measurements, modeling, and observations. The methodology, steps and requirements for assessing the TAIL Index are fully defined in the documents of the ALDREN project [16], [17], [22]. Here, Table 1 summarizes the 12 parameters used to obtain the Index. For the Thermal Environment, the indoor temperature of the dwellings is considered. This needs to be measured in both winter and summer. The Acoustic Environment is analyzed thorough the sound pressure level, determined according to the standard EN 16798 for residential buildings in living rooms and bedrooms. The Indoor Air Quality is the most comprehensive sub parameter of the TAIL Index. It is needed to assess eight different parameters to evaluate the IAQ. The relative humidity and CO2 concentration are measured in both living room and bedroom, as well as the mold, which is assessed through a visual inspection. The particulate matter concentration measurements are mandatory in the living room. On the other hand, the measurement of VOC of Formaldehyde and Benzene, as well as the presence of Radon, are mandatory in the bedrooms. Radon may not be assessed, depending on the location of the dwelling. Finally, the ventilation flow rate needs to be measured in all of the air inlets if the dwelling has a mechanical ventilation system. The last parameter of the TAIL Index is Visual Comfort, which is assessed through the level of illuminance of the rooms and the daylight factor.
Table 1 also shows the categorization of each parameter of the TAIL Index. As depicted in this table, there are four different categories for each parameter. Category IV, in red, is the worst category, while the best category is category I, in green. The main references for these quality levels are the EN standard 16798-1, World Health Organization (WHO) Guidelines for Indoor and Ambient Air Quality and Level(s).
The methodology for calculating and understanding the TAIL Index has thus been presented. Further information regarding the calculation methodology and requirements may be found within the literature indicated in this work. As explained before, the main aim of the TAIL Index is to assess the IEQ in buildings undergoing deep energy renovation. In this work, we analyze the suitability of applying the TAIL Index to dwellings of social housing buildings before undergoing the renovation. The TAIL Index may suggest prioritizing different renovation measures, depending on the results.

Table 1: parameters and ratings of the TAIL Index.

Acronym	Parameter	Unit	Information about the measurement process	Categories of the TAIL Index			
				I	II	III	IV
Thermal comfort, T	Temperature [1]	°C	During warm season (no mech. cooling)	[21, 23]	≥20 & ≤24	≥19 & ≤25	Others
			During cold season (mech. cooling) *Use of standardized termohygrometer is needed.*	[23.5, 25.5]	≥23 & ≤26	≥22 & ≤27	Others
Acoustic comfort, A	Acoustic Comfort [2]	dB(A)	Living-room	≤25	≤30	≤35	Others
			Main bedroom *Use of standardized acoustic meter is needed.*	≤ 30	≤ 35	≤ 40	Others
Indoor Air Quality, I	CO_2 (above outdoors) [2]	ppm	Living-room	≤ 550	≤ 800	≤ 1350	Others
			Main bedroom *Use of standardized acoustic meter is needed.*	≤ 380	≤ 550	≤ 950	Others
	Relative Humidity [1]	%	*Use of standardized termohygrometer is needed.*	[30, 50]	≥25 & ≤60	≥20 & ≤60	Others
	Ventilation Flow Rate [4]	h^{-1}	*Use of standardized thermoanemometer is needed.*	ACH ≥ 0.7	ACH ≥ 0.6	ACH ≥ 0.5	Others
	Mold [1]	cm^2	*Visual inspection is needed*	0	<400	<2,500	Others
	Particulate matter PM2.5 [3]	µg/m^3	*Use of standardized particles' meter is needed.*	<10	≥10	-	≥25
	VOC Formaldehyde [2]	µg/m^3	*Use of standardized Folmaldehyde concentration meter is needed.*	<30	≥30 & <100	-	≥100
	VOC Benzene [2]	µg/m^3	*Use of standardized Folmaldehyde concentration meter is needed.*	<2	≥2 & <5	-	≥5
	Radon [2]	Bq/m^3	*Standardized procedure to measure Radon concentration is needed.*	<100	≥100 & <300	-	≥300
Visual Comfort, L	Illuminance [3]	%	% of the day with 300-500 lux	[100, 60]	(60, 40]	(40, 10]	<10
			% of the night with 100 lux *Use of standardized luxometer is needed.*	0	≤50 & >0	≤90 & >50	>90
	Daylight factor [1]	%	Daylight factor during daytime *Simulations and calculations are needed.*	≥5.0	≥3.3	≥2.0	Others

1 Measurements in living-room and main bedroom are mandatory.
2 Measurements are optional in living-room and mandatory in main bedroom.
3 Measurements are mandatory in living-room and optional in main bedroom.
4 At all air inlets if presence of a mechanical ventilation system.

2.2 Description of the sample

The TAIL Index has been evaluated in four different dwellings of a social housing building selected as demonstrator, located in the city of Vitoria-Gasteiz, in the Basque Country. The selection of these dwellings has been done to obtain a representative sample of the typologies of dwellings within the building.

Table 2 indicates which parameters of the TAIL Index have been assessed in each of the analyzed dwellings, as well as the measurement period. As depicted in this table, the majority of the parameters could be assessed in D1 and during the longest period of monitoring. In D2, a long monitoring period is also available, but only the T, HR and CO2 could be measured.

Finally, in dwellings D3 and D4, a more comprehensive monitoring was performed, over 14 days, which is the minimum required by the TAIL Index methodology. Radon measurements were not needed due to the location of this building.
As indicated in Table 1, the measurements should be performed during both winter and summer. However, for this study, it was only possible to take measurements during the winter, again due to the short availability of the dwellings.

Table 2: measurements, periods and parameters assessed in the demonstrator dwellings.

	Dwelling	D1	D2	D3	D4
Measurement period	Start	01/12/2022	01/12/2022	17/01/2023	17/01/2023
	End	31/01/2023	16/01/2023	31/01/2023	31/01/2023
	Number of days	61	46	14	14
TAIL Index Measurements	T, HR and CO_2	Living room and bedroom	Living room and bedroom	Living room and bedroom	Living room and bedroom
	Pollutants PM2.5	Living room and bedroom	None	Living room and bedroom	None
	VOC Formaldehyde and Benzene	Living room and bedroom	None	Living room and bedroom	Living room and bedroom
	Sound pressure level	Living room	None	None	None
	Luminosity	Living room and bedroom	None	None	Living room and bedroom

3. RESULTS

In this section, we first present the results of the TAIL Index assessment in each of the demonstrator dwellings. Then the result for the overall assessment of the TAIL index of the building is shown. As indicated in Table 2, it was not possible to measure all the parameters of the TAIL Index in each dwelling, so the results shown in Table 3 contain some gaps.

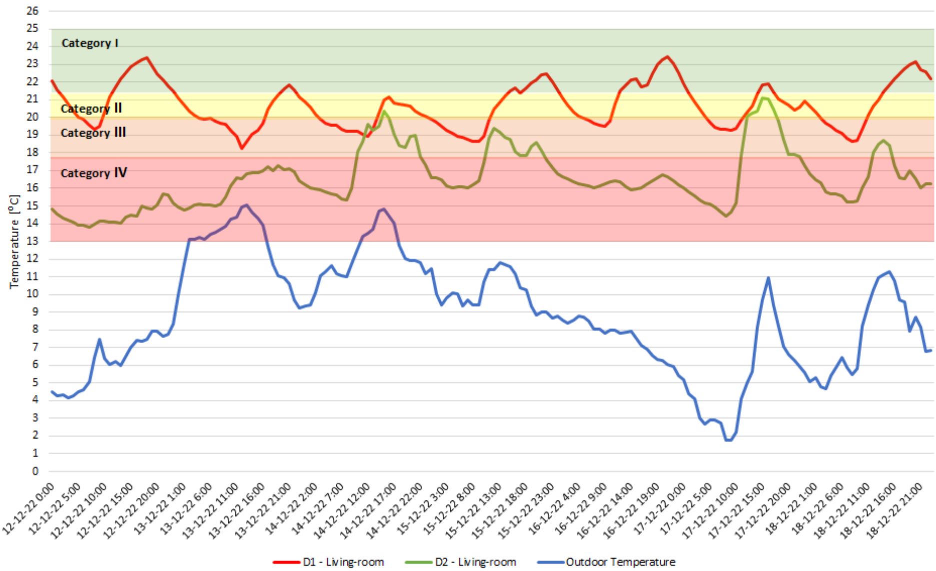
Table 3: results of the TAIL Index assessment in each of the demonstrator dwellings

TAIL Index	Parameter	Dwellings			
		D1	D2	D3	D4
Thermal comfort, T	Temperature	III	IV	IV	IV
Acoustic comfort, A	Acoustic Comfort	II	-	-	-
Indoor Air Quality, I	CO_2	III	IV	III	IV
	Relative Humidity	III	IV	IV	IV
	Ventilation Flow Rate	IV	IV	IV	IV
	Mold	I	I	I	I
	Particulate matter PM2.5	IV	-	II	-
	VOC Formaldehyde	I	-	I	I
	VOC Benzene	IV	-	II	I
Visual Comfort, L	Illuminance	IV	-	IV	-

As depicted in Table 3, the thermal comfort is really bad in all of the dwellings for the monitored period, since the category of the TAIL Index is IV for dwellings D2, D3 and D4, and is category II for dwelling D1, which used heating. This means that, during most of the monitored period, the indoor temperature did not reach 18 ºC in any of the dwellings. This may be surprising, but it is the reality in most of the social housing dwellings. Figure 2 shows the indoor temperature of the living room in D1 and D2 during a week of December 2022, together with the categories of Thermal Comfort. As depicted, the indoor temperature of D2 is really low the entire week.

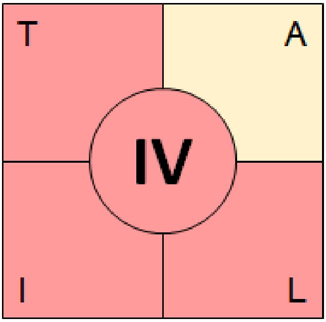
The indoor temperature of D1 is better; the heating periods can be depicted, but are not good enough to achieve a better category of the TAIL Index.

Figure 2: temperature of the living room in D1 and D2, and outdoor temperature, during a week in December 2022.



The Acoustic comfort was only measured in the living room of one of the dwellings. The results of the sound pressure level indicate that the Acoustic comfort is not a significant problem for this building (or dwelling). Regarding the parameters of the Indoor Air Quality, most result in bad quality levels of the TAIL Indicator. Both the CO2 concentration and the relative humidity result in categories III and IV. Since there is no mechanical ventilation in the building, the category for the ventilation flow rate is directly the lowest one (category IV). The results for the visual mold inspection are good (category I), since no evidence of the presence of mold were detected in any of the inspected rooms. The results for the PM2.5 particulate matter analysis show that the conditions in D3 (category II) are better than the conditions in D1 (category IV). This was expected, since the tenants living in D1 are smokers and lived with pets in the home. The analysis for the concentration of Formaldehydes is not worrying in any of the dwellings, whereas the results for the concentration of Benzene is in accordance with the results for the PM2.5 particulate matter. Finally, the results for visual comfort, regarding Illuminance, are also in the lowest level of the categories. This is also expected, since whenever the technicians accessed the dwellings, the blinds in most of the rooms of each dwelling were down.
These are the results for each dwelling if assessed separately with the TAIL Index indicator. Figure 3 shows the overall result of the TAIL Index for the building. As expected, the result for the overall building is category IV, since most of the sub-parameters are also category IV. This scheme allows the IEQ of the building to be assessed at a glance. It is evident that important renovation measures are needed to improve the IEQ aspects of the building. When proposing renovation measures, actions considering the Acoustic Environment may not be prioritized.

Figure 3: overall TAIL Index for the demonstrator building.



4. DISCUSSION

In the previous section, the results of the TAIL Index were shown for each dwelling and for the overall category of the building. In this section, we discuss the advantages and disadvantages of this IEQ indicator, and we provide some suggestions for future revisions of its application in social housing buildings.

Advantages:

•Comprehensive indicator: one of the main strengths of the TAIL Index is evident: it is a comprehensive indicator, which provides a total assessment of the IEQ of a dwelling or building. There are no other IEQ indicators, which summarize the Thermal Environment (T), the Acoustic Environment (A), the Indoor Air Quality (I) and the Visual Environment (L), and then integrates them into one single index describing the overall quality of the indoor environment.

•Based on real in-situ measurements: another of the main strengths of the TAIL Index is that the majority of the indicators are based on real in-situ measurements. This aspect makes the results more accurate, thus providing greater confidence in them.

•Different levels of assessment: as shown in this work, the TAIL Index is assessed individually in different dwellings and then the results are integrated into one single score for the building. This allows specific problems in particular dwellings to be identified, not only focusing on the overall picture of the building.

•Assessment of renovation measures: finally, the TAIL Index was initially designed to assess the renovation of buildings. It has been shown that, thanks to the comprehensive overview, the results allow the focus to be concentrated on one or other aspect of the renovation of the building. For instance, the acoustic insulation may be more important than the thermal insulation; or the particulate matter concentration may need to be assessed; or the VOC of formaldehyde may indicate that the quality of the furniture is not good enough.

Disadvantages:

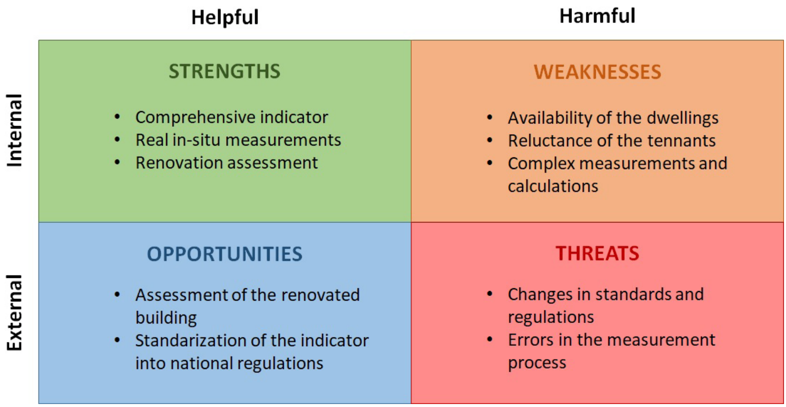
•Availability of the dwellings: the most obvious disadvantage regarding the use of the TAIL Index in social housing buildings is the availability of the dwellings to carry out the needed measurements. As described in the methodology section, several items of equipment need to be installed in the dwellings. Some tenants are reluctant to allow access to their dwellings, which makes it difficult to install the complete set of equipment, more so taking into account the fact that several monitoring periods are necessary to carry out a complete analysis. In addition, social housing buildings are characterized by a high rotation of the tenants. Thus, the tenants in the summer and winter campaigns may not be the same, which can affect the results.

•Representative sample of the building: as described in the introduction and methodology section, the TAIL Index was firstly designed to assess the IEQ in tertiary buildings. Obtaining a representative sample of rooms or spaces within a tertiary building is simpler than in a social housing building, because of the user profile. Furthermore, in a tertiary building, there is no reluctance on the part of the users to assess the TAIL Index. Thus, in social housing buildings, it is more difficult to obtain a representative sample, because the diversity of both user profiles and the typologies of the dwellings within the same building.

•Cost of the equipment: the cost of the technical equipment needed to carry out the measurements is not low. Some of the pieces of equipment are expensive and some of them also need periodic maintenance. There are also some indicators, such as the VOC Benzene and Formaldehyde, for for which the measurements have to be outsourced.

•Complex calculations: finally, not only high quality measurements are needed to assess the TAIL Index, but also data analysis and complex calculations need to be performed to obtain accurate results. This means that the technicians who evaluate this indicator must be competent in the matter.

Figure 4: SWOT analysis of the suitability of the TAIL Index in social housing buildings.



The main advantages and disadvantages of the use of the TAIL Index have thus been discussed. Figure 4 summarizes, in a SWOT analysis, the different aspects discussed. Still further research and in-depth studies are needed to analyze the suitability of this indicator in this type of buildings for a final adaptation. The applicability of some indicators in dwellings could be reviewed, for example, the light environment. This parameter is suitable for tertiary buildings such as offices, but in dwellings the traditions or customs of the tenants can sometimes cause this parameter to be distorted.

In addition, the need to take measurements in two different campaigns (winter and summer) significantly complicates the measurement process. It could be revised so that a single campaign would be sufficient. Depending on the location of the building, for example, the heating or cooling campaign could be prioritized.

In the end, it has been proven that the TAIL Index is a comprehensive indicator to assess the IEQ in social housing buildings, providing a clear insight into the indoor quality of the dwellings. If its use continues to be developed in this type of buildings, it could become integrated into national regulations and help to achieve significant improvements in the IEQ of dwellings.

5. CONCLUSIONS

The TAIL Index assesses the Thermal Environment (T), the Acoustic Environment (A), the Indoor Air Quality (I) and the Visual Environment (L) separately and then integrates them into one index describing the overall quality of the indoor environment of a dwelling or building.

It was first developed to assess the IEQ in offices and hotels undergoing deep energy renovation. In this study, we assess the suitability of this methodology in social housing buildings. In order to do so, four dwellings were selected in a demonstrator building and the TAIL Index was assessed in them.
The results allow us to identify the main sources of discomfort and health problems within the dwellings. The real in-situ measurements provide greater confidence and accuracy to the results. Furthermore, the overall score of the TAIL Index provides a picture of the IEQ of the building and allows renovation measures to be prioritized.
Several advantages and disadvantages of applying this methodology in social housing buildings were identified. The main advantages are evident: they are the comprehensiveness of the indicator and the accuracy of the measurements. Regarding the disadvantages, it was difficult to choose a representative sample of dwellings within the building, while the reluctance of some tenants to carry out the measurements delayed the development of the analysis.
In the end, the usefulness of the TAIL Index on assessing the IEQ of buildings is clear. However, further case-studies of this indicator in social housing buildings are needed to determine if it is suitable or not for this type of buildings. Some aspects need to be revised or improved so as to integrate or standardize this indicator into national certification schemes.

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