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Mediterranean Architecture and the Green-Digital Transition

Selected Papers from the World Renewable Energy Congress Med Green Forum 2022

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Contents

Part I
CITIES: Healthy, Augmented and Resilient Cities

Toward Sustainable Regeneration in Central Urban Areas

Derya Oktay

1 Introduction

Cities are entering a new era; their role expands, becoming nodes in a global competitive network, centers of activity, and places of consumption. Within this context, urban regeneration in the derelict areas of the central urban areas is of great significance.

Urban regeneration has been encouraged by many localities to attract people back to cities and persuade others not to leave through significant construction and aesthetic investment in central areas of cities. However, it is questionable whether these activities are leading to actual lasting change, whether they contribute to the making of livable places, and whether the impacts of regeneration compromise the sustainability of the area or the city.

A contained, well-connected, mixed-use city is advocated by many as the most sustainable urban form, being highly important for sustainable urbanism. A compact city offers opportunities to reduce fuel consumption for traveling, like homes, work, and leisure facilities are closer together; urban land can be reused, while rural land beyond the urban edge is protected. Compact cities with higher densities are also associated with economic benefits, due to high concentrations of people supporting local economics and easier access to services and facilities with diversity, and improved cultural capital [4, 15]. However, since cities are all different in form and structure owing to a host of place-specific factors, the degree of compactness and/or defragmentation should be context-sensitive [12].

In the first two decades of the twenty-first century, in most cases in the world cities, the following characteristics have identified the world cities: As the industry

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has closed, brownfield sites in inner-city locations, be it contaminated or not, and waterfront lands in some cases, have become available for large-scale urban redevelopment ([9], 25). The transformation of these brownfield sites requires sensitive adaptive reuse and huge investment based on a comprehensive masterplan for revitalization for smart densification of the suffering city core. This requires political leadership to attract investment and a holistic understanding of the principles of sustainable urbanism.

2 The Requirements of Sustainable Urbanism

Successfully implemented urban regeneration projects demonstrate that holistic approaches deal with the following issues: (1) densification through "brownfield development," (2) recycling historic complexes/buildings, (3) livable public spaces, (4) good mixed-use and promotion of culture, and (5) ecological sensitivity.

2.1 Densification Through "Brownfield Development"

The term "brownfield" could be defined as any land which has been previously developed, including derelict and vacant land, which may or may not be contaminated ([9], 850). Brownfield development, which is strongly linked to the concept of sustainable development, is the redevelopment of formerly industrially used, derelict sites and docklands, emerges as an effective tool to prevent urban sprawl through densification and defragmentation, and can be considered central to sustainable development as it helps reduce urban sprawl and prevent the greenfield development. Brownfield development would also eliminate negative imagery connected with an industrial heritage as old industrial centers are frequently defined in the media by severe economic and social deprivation, vandalism, public disorder, pollution, and a lack of civic amenities [11].

As Williams and Dair [19] suggest, sustainable brownfield development has been produced sustainably (i.e., in terms of design, construction, and participation processes) and enables people and organizations involved in the end use of the site to act in a sustainable way ([19], p. 28). The objectives of brownfield development could be defined as minimizing the use of resources, minimizing pollution, protecting biodiversity and the natural environment, protecting the industrial heritage, and protecting the cultural environment [3]. A careful brownfield development facilitates mixed-use, takes advantage of compact building design, creates housing opportunities and choices, creates walking distances, fosters distinctive, attractive communities with a strong sense of place, preserves open space, farmland, natural beauty, and critical environmental areas, provides a variety of transportation choices, and makes development decisions predictable, fair, and cost-effective ([17], p. 41).

It should be accepted that a specific legal arrangement both at the local and central government levels is a must to develop appropriate solutions for the sustainable development of brownfields. In line with this, regulations concerned with contamination, liability, and public participation must be added to the environmental legislation as observed in the exemplary cases in the developed countries.

2.2 Recycling Historic Complexes and Buildings

Various transformation projects are planned in various cities of the world in order to revitalize the central urban areas with the old texture and to increase social and economic activity. However, most of these are not addressed with holistic approaches that take into account the physical, social, and economic sustainability of the region. Aiming at sustainable regeneration, it means ensuring development through the renewal of local traditional life, environment, and activities and/or the restructuring of the economic structure of the region, and it requires a detailed analysis of historical structures as well as a comprehensive analysis of the social and economic structure. In this context, a participatory framework and cooperation with other stakeholders should not be forgotten. The historic condition of existing buildings should be respected and viewed as valuable "built resources" and valued with adaptive reuse. Newly proposed, reused, or infilled structures should not be replicas of historical buildings but should be designed with a contemporary architectural approach that reinterprets the original features of historical or traditional structures.

2.3 Livable Public Spaces

As Bentley [1] proposes, "cities exist for processes of communication and exchange between people—that is the only reason for having them in the first place—and public space is a key medium through which these processes take place." Public spaces indeed have an important role as containers of human activity and places of social interaction ([2, 6, 18], p. 386; [5]/1971) and, therefore, play a significant role in the creation of sustainable and livable cities. However, most of the new urbanization examples do not have enough space for them, and most of these areas, which are introduced as "public spaces," lack spatial, ecological, and social qualities. The poor quality of public space and the built environment is directly related to the poor quality of a city's social life, and therefore moral, social, psychological, and economic incentives should be provided for cities to attempt to revitalize their social life [6]. In this context, cultural spaces/streets/squares can be a vital component of the public realm, as they help to establish the identity of a city.

2.4 Good Mixed-Use and Promotion of Culture

As observed in various cities of the world, central regions have lost their livability for various reasons and have become places that only accommodate work and trade. Urban centers have become more problematic places as the residents of the central region move away from them due to various problems they face here and move to the suburbs; buildings were evacuated, lost their functions, shops were closed, most of the social–cultural activities went far from the city center, and, as a result, the central districts turned into areas devoid of security and livability ([10], p. 24).

In a sustainable city, a functional layout that encourages mixed-use should be preferred instead of single-functional models by creating compact city centers with services and facilities within walking distance [7, 8, 16]. This will reduce the need for vehicles and public transport, strengthen social interaction, and reduce demands on infrastructure and energy resources.

When the built environment is combined with culture, it supports the creation of unique and identity places. The time frame for cultural consumption is not limited to the necessities of the normal working day. In other words, cultural activity can be used to create a '24 hour city' as the basis of the evening economy, because it can attract people not only to different places but also at different times, with things like longer store opening hours, evening.

2.5 Ecological Sensitivity

Most architects, town planners, and urbanists do not have the opportunity to design entirely new towns or villages, nor are they likely to become involved in the provision of an entirely new network or hierarchy of urban spaces. Providing solutions with ecological sensitivity in urban regeneration strategies is an opportunity to make places that have not been created with a concept or strategic tendency in this regard, in terms of ecological design. In this context, the spaces belonging to the central texture should be put into the service of the public with appropriate projects, and adaptive reuse possibilities of existing old and historical buildings and complexes should be evaluated. Encouraging concentration in the city center instead of spreading to the areas around the cities that have not been opened for construction before will contribute to the environment and its sustainability in every respect. The use of natural resources and energy, the use of materials with local and regional natural characteristics, the compatibility of the building with the environment and climate, and the renewal and/or recycling of existing buildings while integrating new buildings are the elements of ecological sensitivity.

3 Exemplary Cases

3.1 Ghirardelli Square, San Francisco, USA (1962–1967, 1982–1984)

Ghirardelli Square, which has a history of three centuries and is one of the first examples of the transformation of industrial heritage through adaptive reuse, has been an exemplary model for many new regeneration projects and brownfield developments. The complex, previously housing a wool factory, then a mustard factory, and finally a chocolate factory, consisted of a series of interconnected industrial buildings linked together by several courtyards (Figs. 1 and 2). The complex was redesigned by Wurster, Bernardi, and Emmons, with the preservation of the famous Ghirardelli chocolate factory and its renovation making the traditional production of chocolates open to the public, and its integration with new social–cultural events (restaurants and cafes, cinemas, science center, exhibition hall, sale units, etc.) and outdoors, it has become a point of attraction where local people and tourists spend time with pleasure for 24 hours (Figs. 3, 4, and 5). Ghirardelli's presence in San Francisco landmarks, shops, and restaurant menus has constructed a positive and nostalgic image in people's minds. People from all over the world flock to San Francisco to tour Ghirardelli Square and try Ghirardelli products in booths and many San Francisco residents cherish the name, Ghirardelli. Promoting cultural events and festivals with successful management, the complex has set an ideal example of how the industrial heritage can be exploited.

Fig. 1 The original Pioneer Woolen Building on San Francisco's northern waterfront before it was taken by the Ghirardelli Chocolate Company in 1893. (Source: https://www.ghirardelli.com/about-ghirardelli)

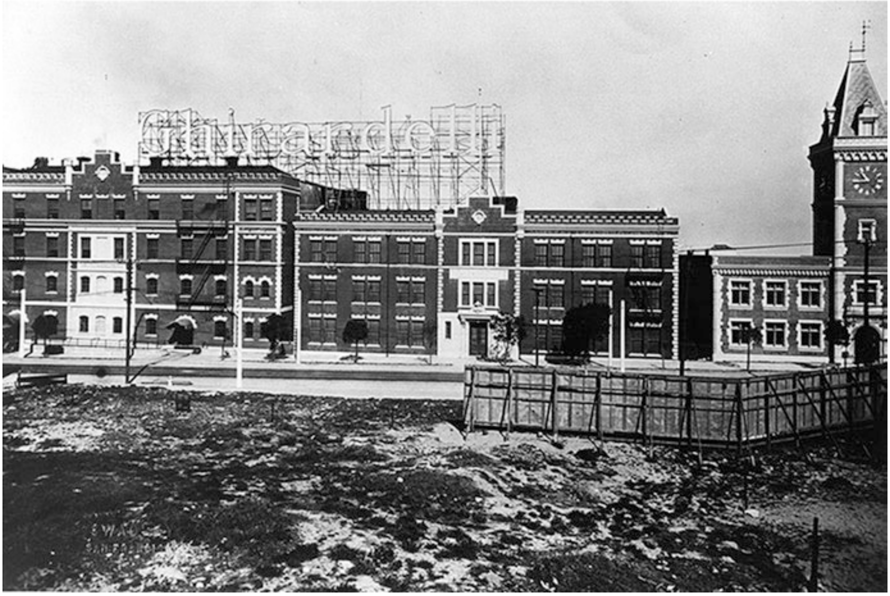

Fig. 2 Ghirardelli Factories in 1936 (Chris Carlsson Collection)

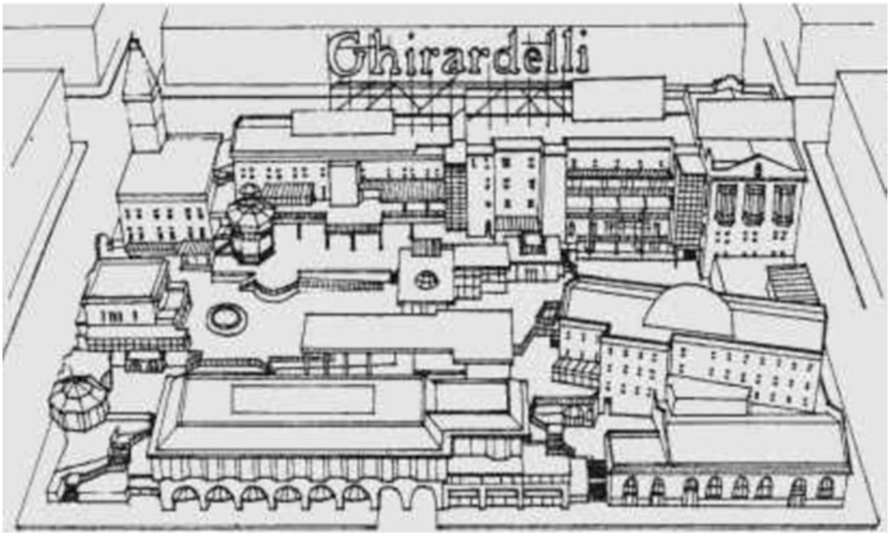

Fig. 3 The layout of Ghirardelli Square after adaptive reuse on the industrial site. (Source:https://www.northernarchitecture.us/urban-design-3/ghirardelli-square-san-francisco-usa-recycling-a-building-complex-19627-19824.html)

Fig. 4 (**a**, **b**) The views to Ghirardelli Square from the street and from the higher level. (Source: Photo by the Author, 1996)

Fig. 5 The view of Ghirardelli Square from the central courtyard. (Source: Photo by the Author, 2008)

3.2 Bulvar Shopping and Recreation Centre, Samsun, Turkey (1887, 2009–2012)

Bulvar Shopping and Recreation Centre is one of the successful brownfield development projects in Turkey, through which the city of Samsun has enlivened its decaying city center. The project, based on a successful adaptive reuse scheme in the former Regie Tobacco Factory complex, the first industrial complex in the city, was awarded at the ICSC European Conference in 2013 the "Best Rehabilitation Project Jury Special Prize" among the newly developed projects in the category of medium scale. The Regie Tobacco Factory was built in 1897 by the Regie

Management. It was the symbol of Samsun's agricultural history for 85 years and had a strong effect on people's daily lives, collective memory, and urban identity (Figs. 6 and 7). The factory, after 12 years of abundance following its closing in 1994, has successfully transformed into a multifunctional commercial and

Fig. 6 Regie Tobacco Factory: the first industrial complex in the city, 1887. ("Post card"—Source: Samsun Metropolitan City Municipality Archive)

Fig. 7 Regie Street in the 1880s (Samsun Metropolitan City Municipality Archive)

recreational complex between 2009 and 2012 and opened in July 2012 as a multifunctional commercial and recreational center following the restoration works by Torunlar GYO and Turkmall.

The complex, covering an area of 17.500 meter-square, was built with reinforced concrete and masonry construction technique designed with a courtyard plan system within a hierarchy of outdoor spaces of different sizes. In all the blocks in the complex, the floor covering is wooden, and the roof covers are traditional-style tiles. In all blocks, doors and windows are wooden, and stairs are reinforced concrete.

Today’s Bulvar Shopping and Recreation Centre, developed from Regie Tobacco Factory as a multifunctional complex (2009–2012) and linked to the main square, marks the city center by providing a popular place for gathering, shopping, dining, and passing the time (Fig. 8). The most outstanding feature of this lively complex is its human-scale form comprising several plazas, courtyards, and pedestrian streets interlinked to each other and defined by active edges provided by cafes, restaurants, and shops.

Fig. 8 (**a**–**c**)The successful adaptive reuse scheme: from Regie Tobacco Factory (Source: Samsun Metropolitan City Municipality Archive) to Bulvar Shopping and Recreation Centre (Source: Photo by the Author, 2015, 2019)

The complex, the major public space of the city, could be considered the living heart of the city that is missing in many cities in Turkey and other countries, and the development of the pedestrian street in the complex is a very successful example of transformation without damaging its identity. The complex, which has become a multifunctional trade, shopping, and recreation center, makes a strong contribution to the identity, function, and vitality of Samsun city center today while contributing to the city's social and economic transformation [13].

3.3 The High Line, New York (1999–2011)

Built on a derelict railroad in Chelsea, the High Line was a collaborative effort between James Corner Field Operations, Diller, Scofidio + Renfro, and Piet Oudolf. As stated by Scherer [14], building the park required stripping the old railway down to everything but its bones and creating an entirely new landscape that functions as a park, pathways, and gathering spaces all at once.

The High Line is the perfect example of sustainable regeneration. The cross section has multiple layers; a porous drainage layer, gravel, filter material, subsoil, and upper soil layers. The materials used in the High Line have been selected for sustainability, considering their lifetime and long-term gain. Circulating water is used in some parts of the area. Plant species that are native, drought resistant, and

Fig. 9 The view of the elevated tracks at West 13th Street in New York in August 1915. (Photo by G. Grantham Bain, in https://www.shorpy.com/node/4794)

Fig. 10 (**a**–**c**) The High Line, New York. (Source: Photo by the Author, 2019)

suitable for microclimate and those that require less irrigation were preferred. The benches are made from sustainable resources. Some old buildings around the High Line were also reused.

The High Line's strong connections with its surroundings, its accessibility, wheelchair compatibility, and location between two magnet areas, together with the support of cultural centers on the line, make it an excellent attraction especially for young people and visitors of the city (Figs. 9 and 10).

4 Conclusions

Successfully implemented urban regeneration projects demonstrate that a holistic approach is essential for sustainable development. In this context, the first necessary step is "densification through brownfield development". This includes providing that historic complexes and buildings are properly reused, public spaces are retrofitted as livable places, good, compatible mixed-use is encouraged, culture is promoted, and ecological sensitivity is safeguarded". Ecological sustainability efforts must be embedded in all phases of urban regeneration and recycling old and historic buildings to safeguard sustainability. Further, the environmental legislation needs to be enhanced with additional regulations concerned with contamination, liability, and public participation issues.

The analyzed examples of urban regeneration through brownfield development reveal that their success continues if there is good management promoting social and cultural activities. Behind all schemes are different experiences, decisions, and dynamics, and all are places that contribute to the creative economy and focus on production.

References

1. Bentley, I. (1999). *Urban transformations: Power, people and urban design*. Routledge.
2. Bentley, I., et al. (1985). *Responsive environments*. Architectural Press.
3. Dixon, T. (2007). The property development industry and sustainable urban brownfield regeneration in England: An Analysis of Case Studies in Thames Gateway and Greater Manchester. *Urban Studies, 44*(12), 2379–2400.
4. Duany, A., Plater-Zyberk, E., & Speck, J. (2001). *Suburban nation: The rise of sprawl and the decline of the American dream*. North Point Press.
5. Gehl, J. (1987, first published 1971). *Life between buildings: Using public space*. Van Nostrand Reinhold.
6. Jacobs, J. (1961). *The death and life of Great American Cities*. Random House.
7. Jenks, M., & Dempsey, N. (Eds.). (2005). *Future forms and design for sustainable cities*. Architectural Press.
8. Jenks, M., et al. (Eds.). (1996). *The compact city: A sustainable urban form*. E&FN Spon.
9. Lehmann, S. (2010). *The principles of green urbanism*. Earthscan.
10. Manzelat, R. R., & Oktay, D. (2019). The quest for livable city centres: A study in Famagusta (Gazimağusa), North Cyprus. *Journal of Civil Engineering and Architecture, 13*(2019), 23–30.
11. Oktay, D. (2012). Urban regeneration and place-making for sustainability. In C. Lamanna (Ed.), *Recycling common ground* (pp. 20–27). Alinea Editrice.
12. Oktay, D. (2017). A critical approach to sustainable urbanism: lessons from traditional and contemporary paradigms. In E. Hepperle, R. Dixon-Gough, R. Mansberger, J. Paulsson, J. Hernik, & T. Kalbro (Eds.), *Land ownership and land use development: The integration of past, present, and future in spatial planning and land management policies* (pp. 295–306). vdf Hochschulverlag AG an der ETH.
13. Oktay, D. (2019). Urban transformation and identity in Samsun, Turkey: A future outlook. *Open House International, 44*(4), 27–35.

14. Scherer, J. (2019). The ultimate guide to the High Line, in https://ny.curbed.com/2019/5/7/18525802/high-line-new-york-park-guide-entrances-map Accessed 5 Aug 2022.
15. Talen, E. (1999). Sense of community and neighbourhood form: An assessment of the social doctrine of new urbanism. *Urban Studies, 36*, 1361–1379.
16. Thomas, L., & Cousins, W. (1996). The compact city: a successful, desirable and achievable urban form. In M. Jenks, E. Burton, & K. Williams (Eds.), *The compact city: A sustainable urban form*. E & FN Spon.
17. Tregoning, H. (2006). It's sprawl, but it's my sprawl. In M. Moor & J. Rowland (Eds.), *Urban design futures*. Routledge.
18. Whyte, W. H. (1980). *The social life of small urban spaces*. Conservation Foundation.
19. Williams, K., & Dair, C. (2005). *Sustainable land re-use: The influence of different stake- holders in achieving sustainable brownfield development in England*, Working Paper No. 4. Cities Unit, Oxford Institute for Sustainable Development, Oxford Brookes University, Oxford.

Urban Regeneration Processes of Public Housing in the Mediterranean Area: A Multiscale and Multisystem Approach

Alessandra Battisti, Angela Calvano, and Andrea Canducci

1 Introduction

Against the backdrop of global and in particular European consumption, the building sector is responsible for 40% of total energy consumption and 36% of greenhouse gas emissions. Moreover, in recent decades, the risks associated with climate change call for the adoption of adaptation measures for urban settlements, on the one hand, and the identification of mitigation measures, on the other, with the control and abatement of pollutant sources and the elimination of the causes of excessive global warming, through the capture of greenhouse gases and the reduction of energy needs of buildings.

In the current context, the transformations induced by climate change on the environmental system and the health of inhabitants, together with the effects caused on the built environment, aggravated by the spread of COVID-19, constitute the elements of a condition of structural polycrisis. In fact, climatic and pathogenic environmental impacts affect the most vulnerable places with limited resilience to environmental shocks [1]. The COVID-19 pandemic has highlighted the fragility of a system unprepared to respond systematically, articulately, and effectively to a sudden health crisis and to the complex and combined effects of climate change and has highlighted the need for a reorganization of spaces to counter environmental, climatic, and pathogenic impacts, in the short, medium, and long terms.

Working on the consolidated city involves changes, from the local level to a wider scale, and becomes fertile ground and catalyst for opportunities in terms of

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regeneration of the urban fabric, driving ambitious measures to adapt, mitigate, and combat climate change [2].

In this context, the complexity of the environment, built and unbuilt, necessarily requires innovative and multidisciplinary approaches capable of carefully investigating the interactions between components, taking into account the changing conditions of the built environment [3]. Today, more than ever for complex interventions such as these, characterized by fundamental structural deficiencies, it is necessary to have a large amount of data available, as a starting point for the project, which through an oriented selection and reading allows the identification of regeneration strategies and the consequent identification of flexible, site-specific and resource-based paths, which pass through an open dialogue between citizens, politicians, technicians, and stakeholders to assess impacts from different perspectives [4].

2 International and National Framework

According to studies and research carried out by the main international organizations, OECD and UN, the acceleration of urbanization has strengthened the importance of urban centers and metropolitan areas, considering also that—at present—cities are home to more than half of the world's population, a figure expected to reach two-thirds by 2050 [5]. Cities face many health challenges, including diseases caused by air, water, and soil pollution, traffic congestion, noise, and poor housing conditions. All these situations are further aggravated by unsustainable urban development [6]. However, while these aspects constitute a tangible threat, a careful multidisciplinary assessment of the critical issues also reveals the also tangible opportunity to implement low-carbon integrated solutions in the urban environment, capable of bringing multiple public health benefits [7].

In this perspective, the urban regeneration and redevelopment of the building stock, in most of the Italian territory evaluated in the estimates of CRESME [8] as old and inefficient, are among the key climate strategies to be implemented in order to achieve the long-term sustainability objectives. Already in January 2020, the European Commission launched the ambitious European Green Deal, consisting of a series of measures aimed at making the continent climate neutral (with zero net emissions of greenhouse gases) by 2050, supporting the ecological transition, and "Building a fairer, healthier and sustainable future for future generations" (Ursula von der Leyen, President of the European Commission). An ambitious program that pushes Italy and Europe toward a deep ecological transition and in particular toward an urban regeneration of peripheral contexts, characterized by social fragility, inadequate urban quality, and poor services, rethinking them in a resilient, sustainable, and inclusive perspective, where regenerating takes on the meaning of intervening in a programmatic way on the urban, social, and health aspects.

In line with the New European Bauhaus program, launched in October 2020 by the European Commission,[1] it is essential for regeneration to set new standards, such as environmental and energy sustainability, the circular economy, the quality of materials, and the socioeconomic inclusion of citizens in the project [9]. Canons, which are the basis of an innovative model of urban and social development, aim at encouraging opportunities for experimentation around the theme of the existing architectural heritage to make it healthier, livable, functional, and accessible to all.

3 Context and Case Study

The realization of public housing in the Mediterranean area over time has constituted repeated and fertile opportunities for design experimentation. These interventions, numerous and diversified in size and construction techniques, have redesigned large parts of the municipal territories with the use of specific types of buildings that have determined urban morphologies well recognizable for plant and consistency, although almost never, however, were able to trigger repeatable models of urban organization [10].

In Italy, 66% of the building stock was built between 1945 and 2000. In particular, in the post-war years and the second half of the 1970s and 1980s, we witness the birth of public housing complexes, promoted by *Piani di Edilizia Economica e Popolare* (PEEP), which marked the abandonment of the limited dimension of the building works, characteristic of the 1930s and of the Ina Casa programs. The balanced relationship between open spaces, built-up spaces, and housing types of modest density is radically replaced by a macrostructural dimension that stands as the ordering element of the territory. In an attempt to adapt to demographic expansion and to curb the phenomenon of abusiveness, the built quantities became enormous without having, however, the formal features and the functional richness. The new plants, which also provided for the implementation of collective services and equipment, completed only after years or remained incomplete, have failed to trigger relationships of continuity with the surrounding, accentuating the effect of segregation and separation with the city itself [10].

There are many realizations of real pieces of the city: the Zen (Palermo, 1973), the Vele (Naples, 1975), the Corviale (Rome, 1974), the Sorgane (Florence, 1980), and the Giudecca district (Venice, 1980), a construction that today manifests a widespread social, performance, and energy degradation [11].

The Roman case is exemplary for its building consistency and settlement structure. An analysis of the existing public housing stock shows that 77.8% was built

[1] The European Commission, in addition to launching the initiative, finances the interventions through European funding programs. To these are added the investments allocated to the instruments of the Next Generation EU, such as Piano Nazionale di Ripresa e Resilienza – Recovery Plan, in the national context, which are the engine of massive urban regeneration and regeneration measures to reduce situations of marginalization and social degradation and improve the quality of urban decor and the environmental context.

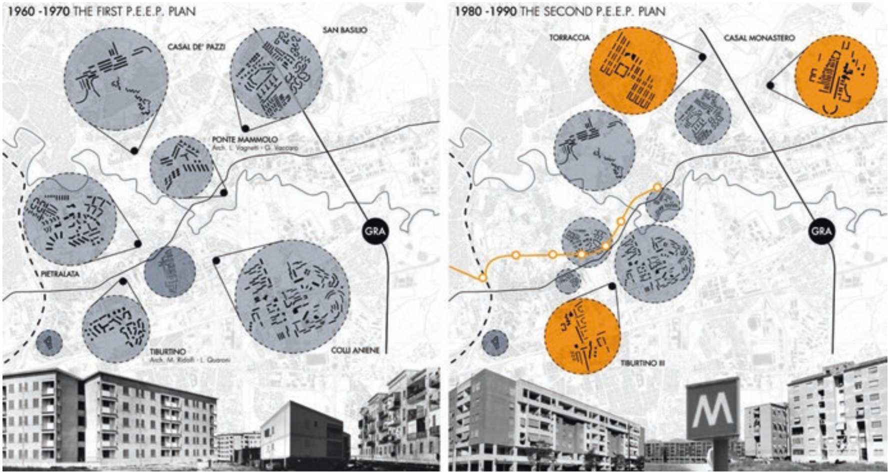

Fig. 1 Development of Public Housing in Rome—northeast quadrant

between 1946 and 1981, in particular 45.9% between 1946 and 1971 and 31.9% between 1972 and 1991. This significant proportion of buildings has been built with insufficient energy standards and with functional standards now exceeded by the use model of the contemporary city [11] (Fig. 1).

Among these, in the northeastern quadrant of the city of Rome, there is the case study of the economic and social housing district of San Basilio, the subject of this research.

On the edge of the Grande Raccordo Anulare highway, but well inserted in the urban structure between Tiburtina street and Nomentana street, the district is the result of subsequent stratifications, starting from the borough built in 1940 and demolished immediately after the war. Different building types and architectural qualities characterize the various blocks of the urban fabric, testifying to a differentiated development occurred as the sum of subsequent interventions. Tower buildings, with star plan, alternate with buildings in line of four or five floors, isolated or aggregated together in various ways to form large green courtyards inside. To the problem of the absence of maintenance policies of buildings are then added other problems such as the poor care of public spaces and especially a total absence of important neighborhood services including green areas equipped, essential for the social life of the community [12].

4 Methodology

In its actuality, the urban project shows itself as a multiscalar principle of coordination between processes and strategies, it does not identify a specific scale but defines a dimension: it measures itself with space and its form, with the relationships between places and contexts, with the sedimentation in the community of elements, not always physical, of permanence. Multiscalarity thus makes it possible to look at physical space as an interaction between space and society, in which scale and dimension define the nature of urban phenomena but also potential intervention strategies [13]. The multiscalar value of the project does not end with its ability to recognize and qualify the multiple levels of interconnection of the project actions. It is through the search for coherence between the various levels of intervention that a fundamental reflection on the quality of the city and its growth processes is exercised [14].

In this context, the present research is the result of a multidisciplinary work conducted within the PDTA Department of the Faculty of Architecture—Sapienza University of Rome, concerning the development of environmental technological intervention methodologies that can build a shared language and approach on the theme of urban regeneration.

The research is articulated on closely related layers—public and private space, outdoor and indoor space—from the urban to the architectural scale in order to define a methodology and formulate meta-project guidelines to be applied to the case study and replicable in similar, peripheral contexts in the Mediterranean area.

The integration of geospatial analyses, supported by Geographic Information Systems (GIS), makes it possible to analyze, represent, and query entities or events occurring on the territory, but also to plan strategies and/or design urban infrastructures. In fact, within geographical software, such as Q-Gis, the common operations that can be carried out on databases, such as searches, statistical analyses, and graphs, are integrated with the functions of GIS, such as the storage of spatial data, their processing, and, above all, their representation in the form of cartograms or tables. In this way, it is possible to analyze and describe complex phenomena that characterize the areas of study.

The proposed methodology is based on a process of inductive and deductive analysis to bring out a framework of resources and criticalities, aimed at planning interventions, at the level of urban space and buildings, aimed at increasing the levels of well-being, social inclusion, and economic development in public housing districts built between the 1970s and 1990s in the Mediterranean area that present strong social and environmental discomforts. The regeneration project is based on the holistic ecological paradigm, according to which the biophysical–environmental system and the social–anthropic system support each other [4], which is why it becomes necessary to understand the complex and articulated structure of the urban context, the object of study, through the analysis of macro-systems, from the large scale to the building scale:

- The study of static data, from sources such as ISTAT and local administrations, the reading of scientific reports, the administration of questionnaires and direct dialogue with citizens make it possible to structure the anthropic system, from a quantitative and qualitative point of view: from the definition of the socioeconomic and demographic structure, to the identikit of those who live there, dwelling on marginality, fragility, and social unease.

- The analysis of the built environment (fabrics, building types, intended uses), the understanding of history (from construction to the present) and the relationship between the peripheral settlement and its closest context and with the city allow the identification of characteristic elements to be maintained and enhanced and those to be adapted and/or adjusted to current needs.
- The identification, mapping, and cataloging of services, first and foremost those of basic necessity make possible to understand the quality of life of residents and eventual users. In fact, public housing complexes suffer from a lack or structural deficiency of services, activities and collective spaces: economic, aggregation and community activators.
- The assessment of accessibility, to the neighborhood or to individual services, and usability define the degree of connection and integration of the complex with the urban system, through the analysis of the rail, road, and sustainable mobility system.
- The quality of life is also and above all linked to the natural environment, public and/ or pertinent green areas, and the presence of vegetation that contribute to combat the phenomena of overheating, absorb CO_2, and provide air cleaning.
- An understanding of climate stability and the effects on the environment and people, through the analysis of microclimatic conditions and sunlighting, reconstructs the general framework and directs interventions in an environmental and sustainable manner.

The macro-systems analysis aims to arrive at a strategic planning taking into account the strengths and weaknesses, opportunities and threats—SWOT analysis—for each component studied. This matrix is the starting point for the construction of a project vision, identified in the metaproject, which operates a synthesis between objectives to be pursued, strategies to be implemented, technological and economic constraints, to achieve sustainable and resilient urban regeneration in the medium and long term.

5 Experimental Application

The experimental application concerns the district of San Basilio in the northeast quadrant of the city of Rome, inside municipality IV (4th). In the northeast quadrant along two main axes, one natural, the river Aniene, and one road, the Tiburtina Street, many economic and social housing districts were built connected only in the 1980s by the underground network and, at the level of *Zona Urbanistica 5E*, it emerges that the area is divided into micro districts, including San Cleto and Torraccia, uneven and each with its own identity. Over time, various projects, of a settlement type, or in the field of public or private mobility or services, have been developed to mend and connect the neighborhoods with each other and with the rest of the city (Figs. 2 and 3).

The district of San Basilio, which since its inception has a predominantly popular connotation, was born in the 1940s as a fascist borough in the Agro-Roman as a

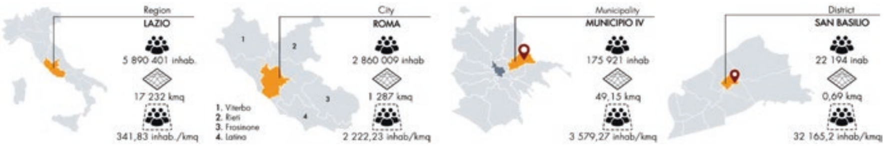

Fig. 2 Case study: San Basilio district—territorial context. (Source: Regione Lazio/Statistica/2018/Popolazione) (Source: Regione Roma/Statistica/2018/Popolazione) (Source: Municipio IV/Statistica/2018/Popolazione) (Source: Z.U.5E/Statistica/2018/Popolazione)

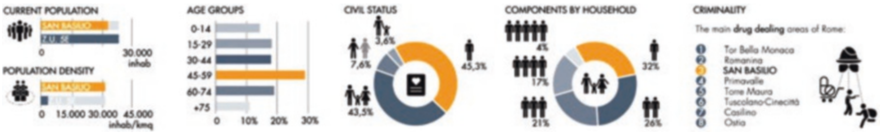

Fig. 3 Case study: San Basilio district—social analysis. (Source: Processing Ufficio di Statistica 31 dicembre 2018) (Source: Data processing "II Messaggero")

result of the urban transformations within the city of Rome: many people were relocated from the historic center to the edge of the city in a non-urbanized context, without services and transport. Over time, the district has undergone various construction interventions that have made it a patchwork of building types and usable spaces. It is home to families of one or more people, middle-aged. There is a high rate of unemployment in the population as one of the relevant data that emerges from the anthropogenic analysis.

The inhabitants of San Basilio live in a neighborhood with a good road system, which is opposed by a hierarchization of the traffic network. The infrastructure network, the road public transport system, and the provision of parking facilities are satisfactory in terms of quantity, but not quality, due to degradation and lack of care.

Poor maintenance also involves green, pertinent and public areas, which represent an untapped value between buildings. The biophysical analysis shows that there are few areas of urban public green for both leisure and sports activities. The green areas available to residents are mainly found in those pertaining to single-family and multifamily homes (Fig. 4).

Services and commercial activities are concentrated in three main areas: the Balena Park, Casal di San Basilio street, and the commercial area of Casal Tidei. The heart of the neighborhood is the Balena Park, the center of community life. Because of the scarcity and lack of variety of services and activities, residents are forced to move. In addition, the continuous growth of the elderly population has made the services dedicated to them insufficient.

The analysis of microclimatic conditions and sunlighting, through the use of software such as ENVI-met and Ecotect Analysis, returns the areas of discomfort, urban heat islands during the summer, and high concentration of relative humidity, caused by the stagnation of water along the evergreen tree axes. The value of the index of the PMV, an index of evaluation of the individual well-being, is however

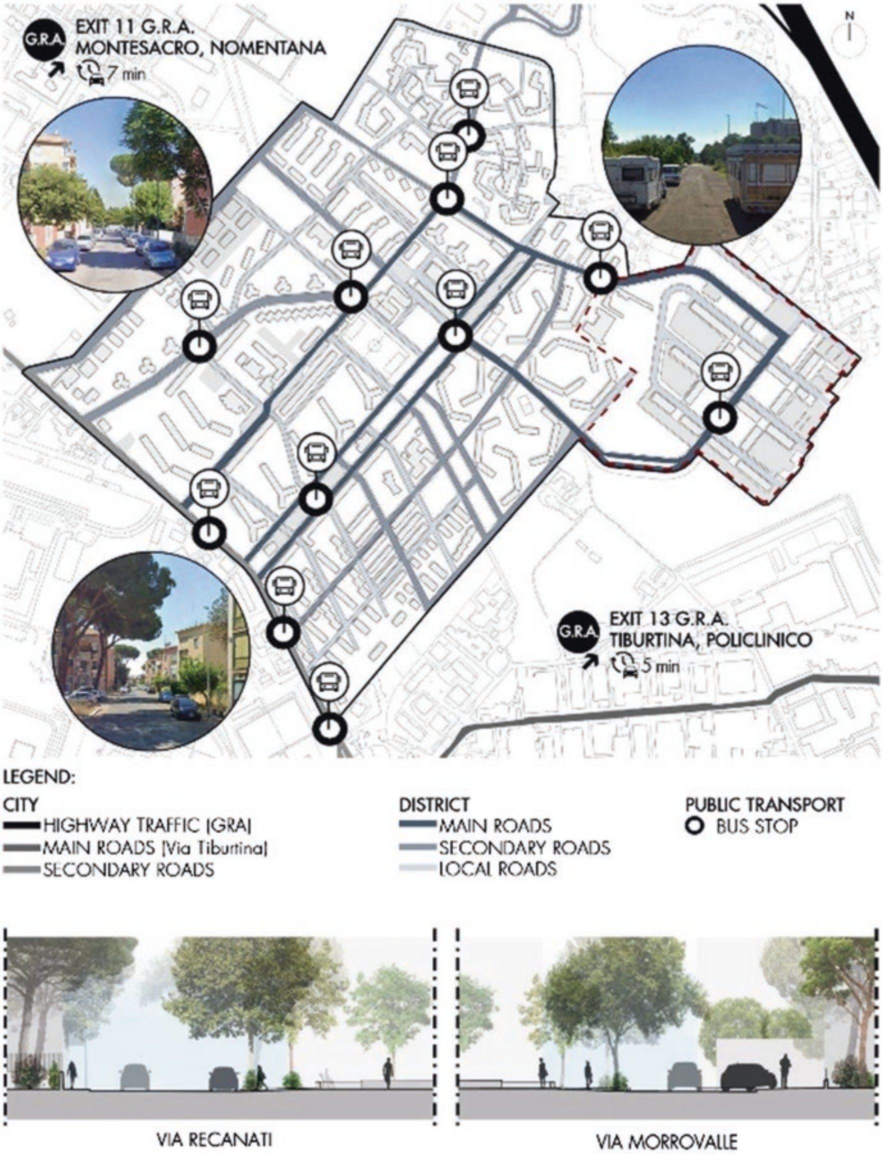

Fig. 4 (**a**, **b**) Case study: San Basilio district—mobility analysis, services, and activities analysis

satisfactory thanks to the conformation of the building and the presence of green courts (Fig. 5).

The process of regeneration underway, by public bodies, is accompanied by a bottom-up process, which starts from the citizens themselves through works of Street Art and initiatives to promote the neighborhood.

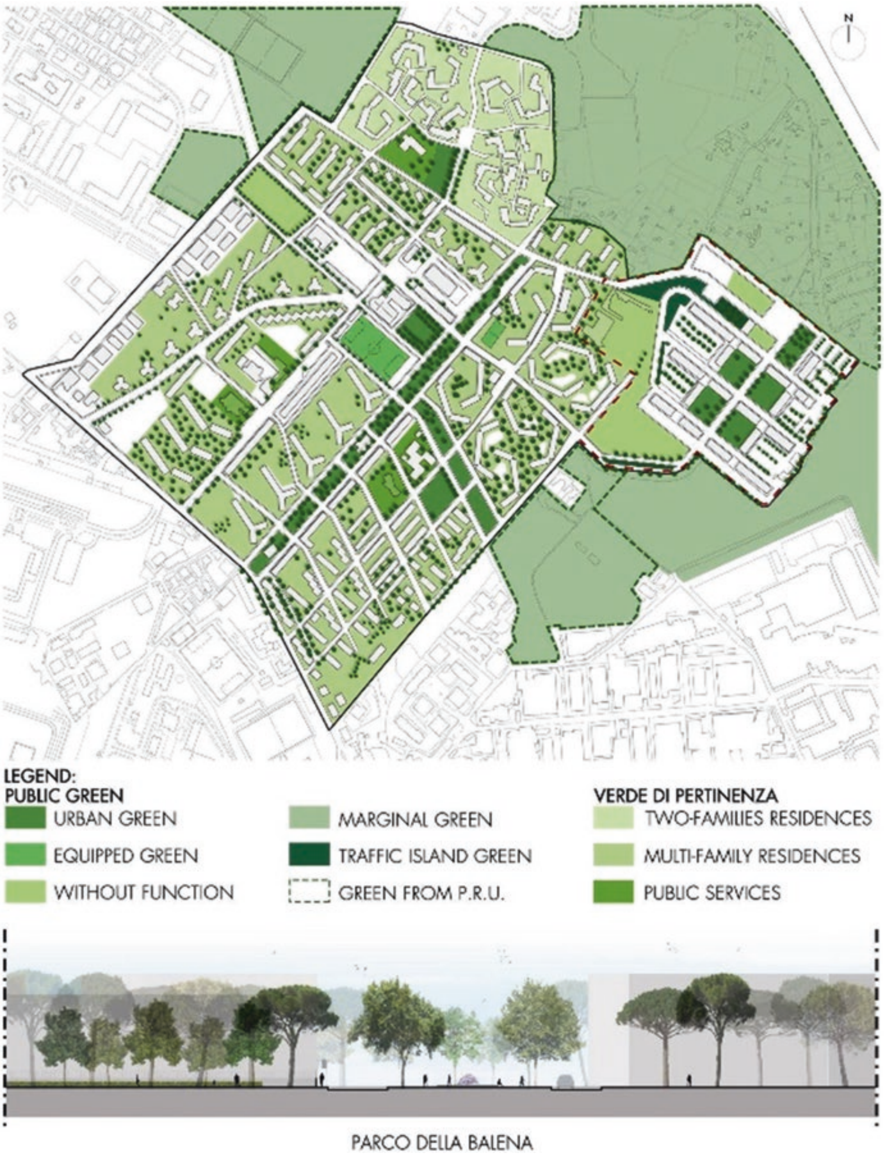

Fig. 4 (continued)

San Basilio is characterized by a strong sense of community in a context of insecurity, by the availability of green areas but abandoned to degradation, by an area plan not integrated with his neighborhood. These elements were the starting point for the construction of a design vision. Objectives and strategies have been defined through the identification of resources and critical issues for each system analyzed. The design focuses on the area of *Piano di Zona* (PdZ) not integrated with the

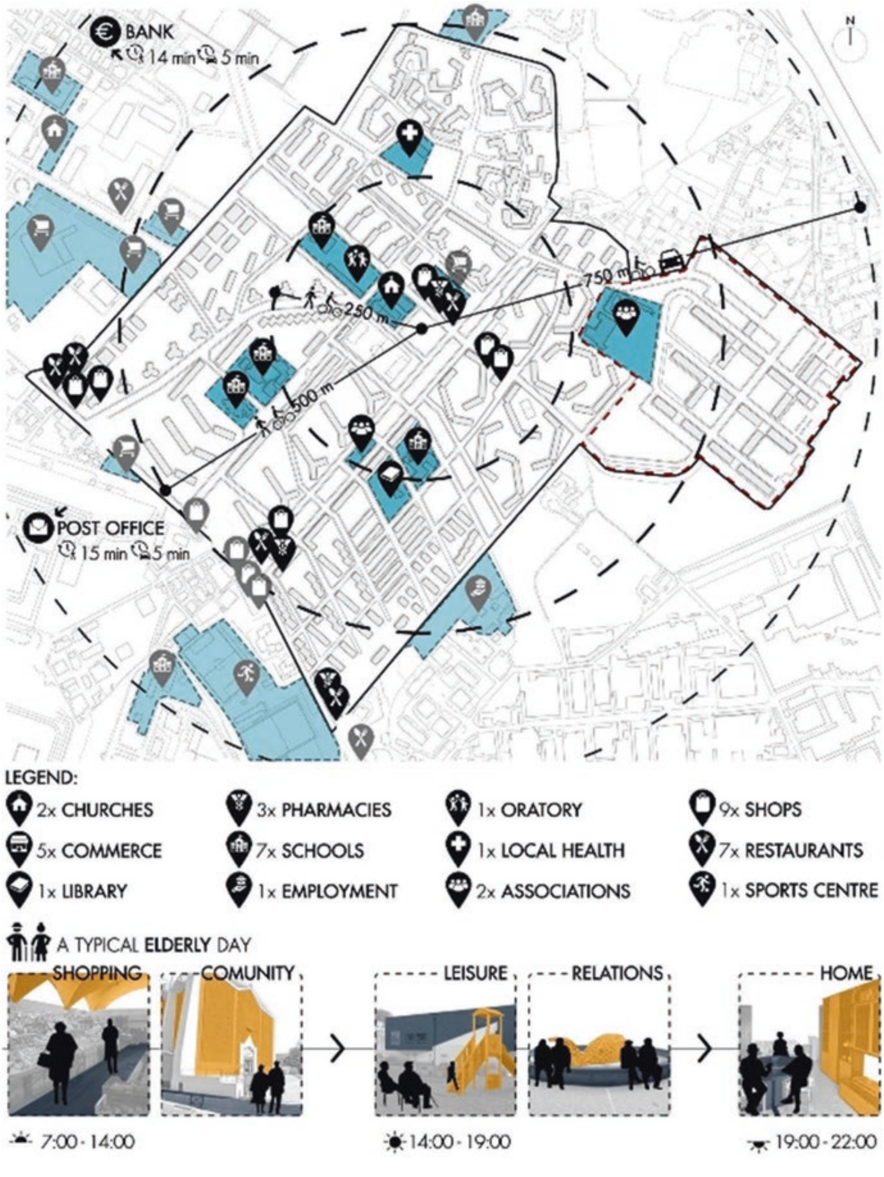

Fig. 5 (**a**, **b**) Case study: San Basilio district—urban green analysis, bioclimatic analysis

district and, in particular, on three areas of intervention of the *Programma di Recupero Urbano* (PRU) of San Basilio and marked as *Ambiti di trasformazione ordinaria* within the *Piano Regolatore Generale* (PRG) of the City of Rome. The intensification strategies for the redevelopment of the district include the configuration of new buildings and public spaces, determined by the considerations emerging

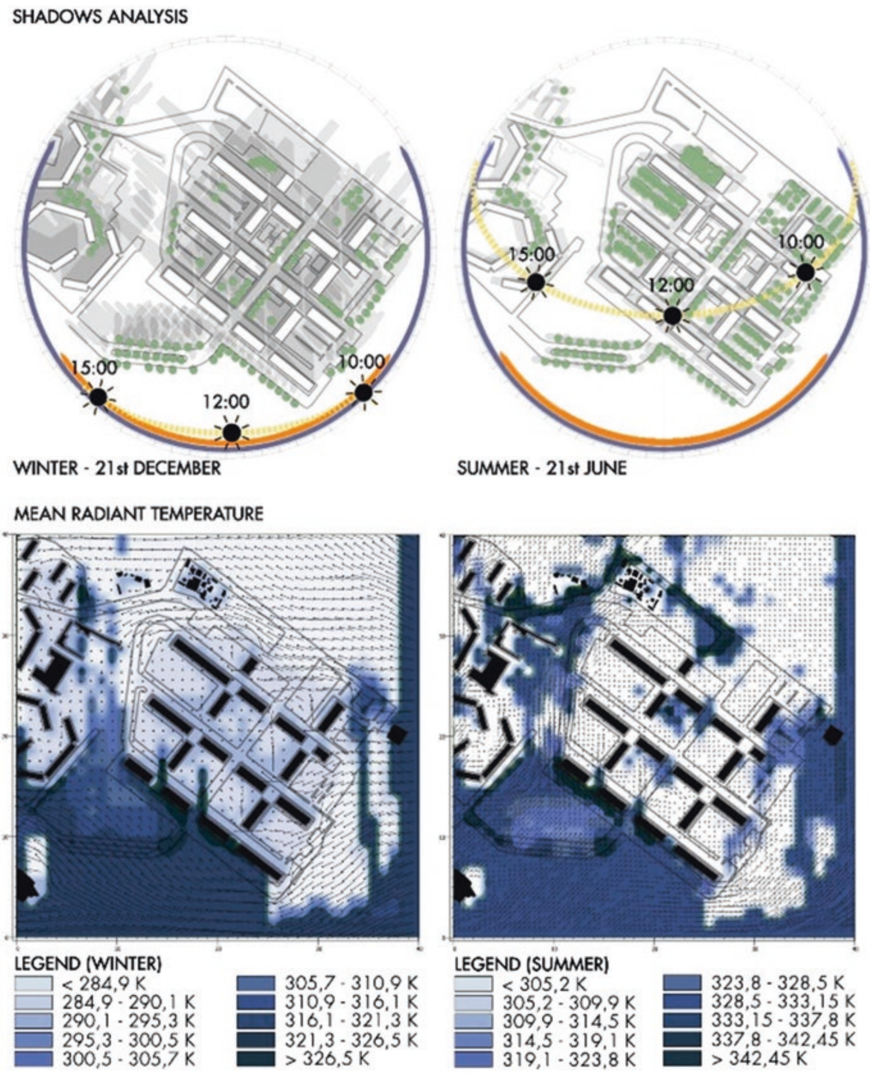

Fig. 5 (continued)

from bioclimatic analysis, sunlighting and ventilation, a careful study of the best construction conformation and the best exposure for each function and environmental unit. Each service, activity, function, and living space has been analyzed in terms of number of users and/or employees, type, radius of influence, time slot, and sizing, according to the *Regolamento edilizio e d'igiene* of the City of Rome, taking also into account the performance requirements through the parameters of environmental comfort, both internal and external (Fig. 6).

Fig. 6 Case study: San Basilio district—meta-project

6 Results and Conclusions

The research proposes the development of an integrated, multiscale, and multi-system methodology, in order to obtain awareness of the applied strategies of urban regeneration. The proposed approach connotes a design quality capable of expressing the relational factors intrinsic to each place and with which the regeneration project must necessarily be confronted and interpreted in order to guarantee a development consistent with the identity of the context of intervention [13].

The recognition of the multiscalar and multisystemic dimension of urban contexts emphasizes the need to conceive transversal, flexible, and relational design logics, in which the configurative quality of a project is the outcome of a process of critical interpretation of the context and its multiform transformative dynamics.

Assuming the centrality of these themes means attempting to redeem the disciplinary self-referentiality that often connotes many projects, affirming on the contrary the need to investigate, through a multiscalar and intersectorial design approach, a context understood not only as a physical space but also as an ecosystem, as an interweaving of actors and decision-making levels, as the set of regulatory, social and cultural aspects that condition the project and its configurative outcomes.

An attitude that reveals a predisposition of contemporary design to read the complexity of territorial phenomena and to design their multidimensionality. An approach that connotes the field of research in a particular way: by continually confronting the empirical observation of phenomena, with cross scaling operations, it focuses, from time to time, the design actions that change with respect to the level of observation, maintaining a coherence with the objectives and strategies set in the meta-project phase. The notion of project scale is therefore identified with the notion of context within which each project to modify the existing acquires meaning and significance [13].

The experimentation applied to the case study made it possible to identify the different degrees of intervention:

- Intervention at the urban scale, at the neighborhood level, was characterized by the upgrading of the street network and pedestrian spaces, the promotion of the functional, cultural, and social aspects of the neighborhood, the redevelopment of green spaces, and the mitigation or facilitation of wind flows with the aim of improving the quality of life of the community.
- The design, on a building scale, has taken into account the criteria of environmental sustainability: from the choice of technologies capable of combining the need to ensure the well-being of users and the use of ecological materials, with the speed of construction and above all optimizing costs, to the application of active, passive, and ecological systems, to allow high-quality standards to be achieved, returning buildings that are sustainable from an energy and environmental point of view.

Within this methodological approach, the components of the project tend to coincide and overlap. An overlap that is now enriched by new themes, which have arisen as a result of the current polycrisis, environmental and pathogenic condition, and quality values within which the notions of multiscalarity and transversality between systems can find further developments and declinations.

References

1. Verde, S. (2022). Scenari multirischio, conoscenza e progetto ambientale per la periferia dell'area nord di Napoli. *Techne. Journal of Technology for Architecture and Environment, 23*, 146–155.
2. Green City Network. (2021). *Verso la neutralità climatica delle Green City*. Approcci, indirizzi, strategie, azioni. Rapporto 2021. Green City Network.
3. Tucci, F., & Battisti, A. (2020). Green economy for sustainable and adaptive architectures and cities: Objectives, guidelines, measures. *IOP Conference Series: Earth and Environmental Science, 503*, 1–5.
4. Mannucci, S., & Morganti, M. (2022). Il DMDU per contrastare le fragilità climatiche. Un'integrazione con il progetto rigenerativo. *Techne. Journal of Technology for Architecture and Environment, 23*, 45–53.
5. UN. (2018). *World urbanization prospects: The 2018 revision*. Key facts. United Nations.
6. D'Alessandro, D. (2020). Urban public health, a multidisciplinary approach. *Urban Health - Participatory Action-research Models Contrasting Socioeconomic Inequalities in the Urban Context, 24*, 1–8.
7. Battisti, A., & Marceca, M. (2020). Urban health multidisciplinary actions promoting health in an urban environment. *Urban Health - Participatory Action-research Models Contrasting Socioeconomic Inequalities in the Urban Context, 24*, 19–26.
8. CRESME. (2022). *Il mercato delle costruzioni*. XXXII Rapporto Congiunturale e Previsionale.
9. Rosado-Garcia, J., Argüelles-Bustillo, R., Kubus, R., & Garcia-Garcia, M. (2021). A new European Bauhaus for a culture of transversality and sustainability. *Sustainability, 13*(21), 11844.

10. Mattogno, C. (2019). La città pubblica a Roma: un catalogo di spazi abitabili. Dalla casa al paesaggio. Edilizia residenziale pubblica e mutamenti dell'abitare a Roma, Gangemi, Roma, pp. 51–77.
11. Lannutti, C., & Corsetti, M. (2013). Sostenibilità energetica ed economica negli interventi di riqualificazione dell'edilizia residenziale pubblica. *Techne. Journal of Technology for Architecture and Environment, 3*, 347–349.
12. Carosi, C. (2019). San Basilio. Dalla casa al paesaggio. Edilizia residenziale pubblica e mutamenti dell'abitare a Roma, Gangemi, Roma, pp. 353–374.
13. Russo, M. (2015). Multiscalarità. Dimensioni e spazi della contemporaneità. *Archivio di Studi Urbani e Regionali, 113*, 5–22.
14. Macchia Cassia, C. (2002). *Attraversare le scale*. Infra Manuale.

Energy Communities and Smart Villages in the Madonie Sicilian Inner Rural Area

Luisa Lombardo

1 The Madonie District and the Energy Communities as Drivers of Smart Villages

The European Union and Italy, today, are promoting the enhancement of marginal areas instead of chaotic cities giving them lots of chances for their development. The "Madonie District" in the Mediterranean area, in the center of Sicily, is an inner rural area composed of 21 municipalities that, in the last years, is suffering due to depopulation and lack of work despite its natural and architectural potential [1]. The pandemic situation has pointed out the necessity of a better life quality that could be guaranteed with the process related to the creation of smart villages, little collaborating urban centers, not so far away from the biggest cities. Towns and villages do not have to be strangers to the digital revolution that is taking place in the world, or at least they should not be because their survival depends on it. Innovative solutions have reached rural areas to help develop and improve their social, economic, and environmental conditions.

The idea behind smart villages revolves around shifting the paradigm so that instead of considering small rural populations as recipients of government aid, they are equipped with the necessary means to become engines of change and productive centers [2]. The determining factor in achieving this is the digitalization of the villages. It is necessary to enhance these territories with sustainable technological design, in order to enable urbanization and digital innovation and to realize a sustainable program of development and being an energy community using technological systems such as solar panels or wind farms and inclusive design aim at obtain a compatible rehabilitation using technologically eco-efficient strategies and

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functional and innovative solutions. Sustainable and renewable strategies are not always satisfactory and in accordance with the architectural heritage in terms of compatibility with natural and built landscape, especially if framing the village under consideration is a protected area such as the UNESCO World Geopark of the Madonie Mountains. Therefore, the challenge at hand is about the coexistence of tradition and innovation, without harming the natural heritage that provides the backdrop for a wonderful context [3] (Fig. 1).

According to the operational definition of the European Network for Rural Development (ENRD), smart villages are "rural communities that use innovative solutions to increase their resilience, building on local strengths and opportunities. They are based on a participatory approach in order to develop a strategy that can improve their economic, social and environmental conditions, taking particular advantage of the solutions offered by digital technologies." They adopt a bottom-up approach, starting with a path of territorial animation that involves the local community and leads to the identification of the real needs of the area, with the aim of implementing interventions that bring concrete benefit to the community [4].

A smart village, in particular, is a community of people living together, collaborating. The issue of energy communities confronts two sides of the same coin: the technological part of the energy community, of competitive advantage, but also the need to have a close-knit cadre of participants both as consumers and as producers [5]. Building communities is a great challenge; it is not easy to form people who want to work together to produce and consume in a limited, cohesive and close space. An energy community is a collection of citizens working together with the goal of producing, consuming, and managing energy through one or more local energy facilities. A number of European Directives and the market are moving to respond to this possibility by encouraging the establishment of energy communities. They constitute a great opportunity from a community, social and environmental point of view because they represent and bring benefits by producing energy from renewable sources, reducing dependence on fossil sources and polluting less, with incentives also economic on shared energy. It also has the role in fighting the poverty of many families and citizens that subsists; they represent an opportunity to

Fig. 1 Gangi, one of the 21 municipalities in the Madonie District. (Author: Luisa Lombardo, 2022)

configure systems in which a community comes together to achieve common benefits. The first step is to stimulate a community of citizens with a heterogeneous network with citizens, administrators and businesses, local merchants, or even religious entities as the new legislative decree proposes to involve the community [6]. The "rules" of the PNRR finance restorations, renovations in terms of energy efficiency and the regions can take charge of a widespread initiative in the territories, which needs to be reactivated starting with energy. This can happen by implementing territorial energy planning [7], with the aim of enhancing local energy resources for the "benefit of communities," explaining to communities the steps to be taken in the design, implementation, operation, and maintenance phases.

2 EUROPE, PNRR, and Energy Community Policies

The PNRR, that is the National Recovery and Resilience Plan, bets on a future made up of energy communities: starting from the areas that were struck by earthquakes in 2016, to Italy's inner rural areas dotted with historic villages and scenic beauty, such as Madonie territory. The economic revitalization of these areas comes through the PNRR, which can ignite hundreds of energy communities in Lazio, Abruzzo, and Marche. This may also happen thanks to the decree that implements the European directive on energy communities, to which is added the measure included in the PNRR, with 2.2 billion euros in incentives, that concerns subsidized-not non-repayable-rate financing in municipalities under 5000 inhabitants that build an energy community within them. And this could also curb—or reverse—the depopulation of these territories; for the inner rural areas related to the South of Italy is a great possibility to emerge as virtuous and smart communities.

The broadening of the requirements introduced by Legislative Decree 199/2021, which implements the European RED II Directive on the promotion of renewable energy, allows small municipalities to aggregate into "inter-municipal" Renewable Energy Communities, so as to increase the production of shared energy and the number of members of the ERC itself. It is an excellent opportunity for Public Administrations to contribute to making their cities more "inclusive, secure, durable and sustainable," as called for by Sustainable Development Goal (SDG) No.11 of the 2030 Agenda, and to combat energy poverty, in line with SDG No.7, which aims to "ensure access to affordable, reliable, sustainable and modern energy systems for all" and give citizens a leading role in the energy sector.

Spain was the first since the approval of the European Directive 2018/2001 to introduce the possibility of collective self-consumption in that same year with Royal Decree Law 15/2018, followed by the Energy Communities legislation in Greece (Law 4513/2018). In northern Europe, there have long been virtuous examples of what is called "community energy" in English: shared energy projects that are wholly or partially owned or controlled by community groups, including energy cooperatives. Denmark, for example, has been a model of collective investment in renewable since 1970. This vanguard led to 40 percent of installed turbines being owned by communities in 2002, and by 2013, this percentage had risen to 80 percent: Denmark's rate of energy capacity from RES thus came to be one of the highest in the world. Germany has focused since the early 1990s on several community-owned solar energy projects to arrive in 2014 with 50 percent community-owned PV generation. A special case mentioned in the "Erneuerbare Energien Gesetz" is collective condominium self-consumption, in which the energy produced and consumed within the building does not go through the public grid, with no debt of system charges to the operator. In 2015, there were an estimated 973 German energy cooperatives for renewable energy production, mainly from photovoltaics.

The energy community is defined as "a legal entity" based on "open and voluntary participation" whose overriding purpose is not the generation of financial profits, but the achievement of environmental, economic, and social benefits for its members or associates or to the territory in which it operates. To ensure the non-profit character of energy communities, energy companies are not allowed to participate as community members; instead, they can provide supply and infrastructure services.

In Italy, Article 42-bis of the so-called Milleproroghe Decree defines the concepts of collective self-consumption and energy community. To promote the use of storage systems and the coincidence of production and consumption, an incentive tariff has been established to remunerate instantaneously self-consumed energy. To qualify for the incentives, the system must be new, that is, installed after March 2020. The incentive tariff will be cumulative with tax deductions and will depend on the type of energy. The renewable energy community must also consist of consumers located in the vicinity of the generating facility and photovoltaic systems and they must have a total capacity of no more than 200 kW. There are incentives provided for energy communities that are also cumulative with other benefits, including measures under the Ecobonus, the 110% Superbonus, and the Home Bonus, with the possibility for businesses, local authorities, and citizens to achieve high economic savings through reduced costs as energy is self-generated, especially on the variable components of the bill: some estimates speak of about 500 euros saved each year on the bill.

We must imagine that if harnessed this potential, in small towns, such as the rural villages of the Madonie, this can be a driving force for their revitalization and enjoyment in economic, social, but above all technological terms. Energy communities in Italy can obtain a tariff benefit for 20 years managed by the GSE—Energy Services Manager—with a unit fee and a premium tariff, the latter being 100 euros/MWh for self-consumer groups and 110 euros/MWh for energy communities. The regulation also provides for the return of some items on the bill for the non-transmission of energy to the grid that these plants allow, resulting in a relief that is quantified as 10 €/MWh for Collective Self-consumption and 8 €/MWh for CERs on shared energy. The sum of all benefits would amount to about 150–160 €/MWh.

In Italy, then, associations of businesses and citizens are taking shape, leaning on the public administration to create small oases of clean, fully self-sufficient energy. Small enclaves that put together can give body and form to a real transition, which, in times of energy dependence on Russia and war in Ukraine, represents a winning strategy. They are called Renewable Energy Communities (RECs), or they can be also associations of citizens, businesses, local governments, or small and medium-sized enterprises that decide to join forces and interests to equip themselves with shared facilities for the production and self-consumption of energy from renewable sources.

According to the Renewable energy report 2022 by the Politecnico di Milano there are currently 26 active communities in Italy with photovoltaic systems. The GSE—Energy Services Operator—has, to date, received 37 applications to access incentives, including 13 renewable communities and 24 groups of self-consumers from Lombardy, Piedmont, and Veneto. To now there are twelve energy communities, mainly concentrated in Piedmont, Veneto, Emilia Romagna, and Lombardy, and the trend is set to grow. In addition, it is estimated that within five years there will be about 40,000 Italian energy communities, involving about 1.2 million households, 200,000 offices, and 10,000 SMEs. The future requires that everyone will be protagonists in the reconstruction, starting with the institutional chain, that allows actors such as citizens, businesses, administrations, condominiums, and third sector entities to get together, produce energy, and exchange it. Region entities must accelerate their work to systematize all these opportunities, with an overall vision of relaunching post-earthquake reconstruction but, above all, relaunching the centrality of our hinterland [8].

3 Finding New Energy Strategies: The Wind Power Opportunity

What are the advantages and disadvantages of solar panels and wind power plants: which one is the best?

But, first of all, how to deal through technology and natural landscape and protect territory like the Madonie [9] one? More and more solar panels of photovoltaic systems, or wind power systems, are appearing on buildings, which are in fact the two most popular renewable energy sources; but which one is more convenient and recommended for domestic use and in particular areas? As far as photovoltaics are concerned, there are certainly important concessions, incentives and economic benefits resulting from bill savings. Their application also has environmental benefits from reduced pollutant emissions; increased property value with minimal maintenance; increased energy independence; and high adaptability with regard to installation. Increased durability and less chance of being damaged by atmospheric phenomena. But we should consider initial investments; energy production varies with the seasons and times of day; they have not an adequate storage system, energy cannot be stored and they have extra cost of the storage system.

For the wind power plant, however, the advantages are mainly economic derived from bill savings; greater speed in energy production; greater reversibility, i.e., possibility of restoring the area occupied by the plant; and increased disposal possibilities; On the other hand, in the absence of wind, their energy production would be interrupted; they sometimes increased visual pollution; the noise of the blades; greater environmental impact, especially for avian fauna, i.e., birds; often local authorities prohibit their installation for the above reasons; fewer incentives and subsidies; more prone to deterioration of mechanical parts over time; and more exposed to harmful weather phenomena.

Today, people tend to install solar panels without thinking about the aesthetic impact on existing buildings, without thinking that in well-preserved inland areas such as Italy's inland areas, or in the Madonie one, these can make a not inconsiderable visual impact. But where there is artistic, historical, or landscape heritage to be preserved, such as the Madonie land, more caution must be exercised. Many Italian municipalities have responded to the problem with precise architectural constraints, but elsewhere the situation is different. The watchword is to diversify implementing other sustainable systems in order to pay attention to the environment and find other opportunities improving new strategies in technologies.

As an example, making wind power a growing renewable source in the international market is the creation of increasingly environmentally and bird-friendly facilities. Wind farms have always been the focus of debates by animal rights activists and environmentalists because such facilities can be a threat to many animals, including sparrows, pigeons, and swallows. Also, not to be overlooked is the problem of noise pollution. With this in mind, Raymond Green has designed a new model of bladeless wind turbine, the Catching Wind Power. Thanks to its innovative design, it will be able to produce clean energy from the wind and protect animals' life at the same time. Catching Wind Power is represented by a large cone positioned in place of the normal blades through which air will be able to be conveyed. Through this patented innovative system, a strong compression will be created at the inlet, such that more power will be brought to the turbine motion. The use of a protective cone, where the blades are mounted inside, will prevent birds from coming into contact with the turbine rotors. Another very interesting aspect is the almost total absence of noise from the rotating wind turbine, thanks precisely to those protection cones that not only act as protection for the life of the birds but also have the function of real silencers of the system. This can be a perfect solution in order to have a sustainable energy resource and try to respect also environmental impact for example in a territory like the Madonie one with so many restrictions related to the territory.

4 The Benefits of the Energy Communities in Italy

The benefits of being an energy community [10] are economic and environmental, because with energy communities one could not only save money on bills, but also make money, all while respecting the environment. Energy produced reduce emissions of CO_2 and other polluting gases. A typical family, in Italy, consumes about

2700 kWh of electricity per year, a photovoltaic system would avoid emissions of about 950 Kg CO_2/year corresponding to the absorption activity of about 95 trees.

Each community has its own characteristics, but all have the same goal: to self-produce renewable energy at affordable prices for its members. The founding principles of an energy community are decentralization and localization of energy production. Citizens, businesses, enterprises, and others in the area can form communities to produce, consume, and exchange energy with a view to self-consumption and collaboration. An energy community has its own energy production facility and consumes what it needs. Excess energy is fed into the local grid to be exchanged with other community members or is stored and returned to the consuming units at the most appropriate time. Individuals in the community must produce energy for their own consumption with systems powered by renewable sources, as in the case of a photovoltaic or wind power plant available to the community, or individual ones, such as a photovoltaic system installed on the roof of a home, business, government office, or apartment building.

ENEA—an Italian public research organization working in the fields of energy, environment, and new technologies to support competitiveness and sustainable development policies—is also now experimenting some tools and applications in the initial assessment of technical and economic feasibility for a self-consumption configuration, and therefore CER, both in terms of the management factor. As the community is formed, there will be also a CRUIS to monitor community behavior and assess its progress automatically. It is important to foster the local economy through a system of exchange of goods and services, a neighborhood hamlet, then based on a sharing economy system. Importance of the energy community within the community is not easy either to manage or to establish, let alone to promote. Energy communities in Italy, finally, make it possible to exchange renewable energy by enabling citizens, governments, small businesses, and associations to be key players in the energy revolution.

At the moment, there are a few energy communities in Italy, with new initiatives coming to life more and more frequently. More than 50 municipalities in Lazio and some municipalities in Rome are implementing the legal basis for the establishment of energy communities on their territory. In Veneto, there is the Cev Consortium with 1100 municipalities throughout the country and 16 Italian energy communities' municipalities.

Another one is the Melpignano Cooperative formed in 2011 through a collaboration between Legacoop and the city government with the aim of producing energy using photovoltaic panels placed on the roofs of public and private buildings in the city. The cooperative also has the responsibility of installing, operating and maintaining the photovoltaic systems, producing energy and taking into account the demand of users who resell the surplus. Pinerolo community, in Piedmont, is another recent energy community project implemented in the Pinerolo, Piedmont area. Municipalities and companies are included in this community, and among them 8 out of 11 are prosumers. The community includes: 15 photovoltaic systems other than domestic; hydroelectric power plants and biogas production. Natural gas is also used, but, in this case, there is a high-efficiency cogeneration system.

GECO—Green Energy COmmunity, Bologna—is the pilot project that will lead to the creation of the Pilastro-Roveri energy community. The project aims to make the energy system local more efficient and resilient, focusing on the figure of the prosumer, the citizen, at the same time producer and consumer of energy from renewable sources. GECO aims to address the social, technical, and economic aspects related to the creation of a green energy community, with the aim of increasing environmental sustainability, reducing energy poverty, and generating a low-carbon economic cycle. And last, CER—Energy City Hall, Magliano Alpi (CN) with its 20 kWh photovoltaic system installed on the roof of the Municipal Building—shares its produced clean energy by acting as the coordinator of the ERC as well as producer and consumer.

In the South of Italy and in the italic islands come other examples of those who have already implemented a renewable energy community with the dual objective of efficient consumption and self-production of energy as did the municipality of Ferla, in the province of Syracuse, the first in Sicily, or that of Biccari, in Puglia in the hinterland in the heart of the Monti Dauni, and then there are those in which the energy community is starting right now as is the case, for example, in the Sardinian municipality of Serrenti.

The Association of Authentic Villages of Italy joins BeComE and aims to make small Italian municipalities protagonists of the energy transition. The principal mission is to offer a tool of aggregation and development to small realities in order to improve their urban structure, services toward citizens, social, environmental, and cultural context, to increase the quality of life of the population: from a widespread information campaign on the theme of energy communities, to training and assistance activities aimed at municipalities, accompanying them in the development of energy and social experiments in the territories, making a leap forward in the name of environmental sustainability and community and social cohesion.

There are three main actions in which BeComE project will be divided. First, the widespread dissemination of the campaign and the topic of CERs to which, on the one hand, will contribute the alliance signed with some of the main networks of certified villages in Italy involving hundreds of small towns scattered across the Boot; on the other, the 2022 edition of "Voler Bene all'Italia," Legambiente's historic campaign in favor of small municipalities, this year dedicated precisely to energy communities. Thanks to these networks, online training courses will then be developed, flanked by in-depth and verification paths by Azzero CO_2. At the same time, ten pilot small municipalities will be selected where a targeted action will be carried out to accompany the formation of Renewable Energy Communities. The ten hubs will also be the focus of the closing event of the BeComE project, scheduled for the Proposals to the Government—Five requests that Legambiente and Kyoto Club have launched today to the Government regarding energy communities: Government and Authority define as soon as possible with the relevant decrees and resolutions the technicalities and incentives essential for the real start of energy communities throughout the country.

5 A Blue Green Energy Project Inside the Madonie Area

One important example to mention is the Blue Green Energy, a project in the municipality of Blufi, one of the 21 small villages approximately 800 meters above sea level, in the heart of the Madonie Mountains [11] near Palermo. With about a thousand inhabitants and known for the wild fennel festival, in the springtime, it sees the surrounding fields turn into a carpet of thousands of wild red tulips, for this reason is called also "little Holland": thousands of red tulips grow wild in a field planted with wheat, among almond and olive trees—an incredible sight. This is the flowering of the Early Tulip or Raddi's Tulip (*Tulipa raddii*). Resistant to soil plowing because of the bulbs' location about 50 cm deep, tulips-wild-bloom generally between March and May and are totally absent in fallow land. The municipal administration, seemingly so distant from the idea of modernity, is actually really projected into the future and has decided to accept Enel X's proposal to establish the first "inter-municipal" Renewable Energy Community, which will involve five other municipalities in the Madonie like Bompietro, Castellana Sicula, Geraci Siculo, Petralia Soprana, and Petralia Sottana [12] (Fig. 2).

The project shared also recounted during the program Linea Verde Link aired on Rai1 in the last April 30, involves the construction of 3 photovoltaic systems on the roofs of municipal school buildings, for a total power of 64 kWp, to which others will be added as soon as possible, made by public or private entities. This will result in the production of about 90,000 kWh per year of clean electricity, which will be shared with an original core of 16 members. The whole will bring benefits: environmental, with reduced emissions of about 29 tons of CO_2 per year; and economic, through the provision by the Energy Service Manager (GSE) of a bonus of 15,000 euros per year, divided for 20 years, to be distributed among the community members; social, with a concrete contribution to saving on spending and reducing energy poverty [13] (Fig. 3).

Fig. 2 Blufi, the little Holland in Sicily. (Author: Luisa Lombardo, 2022)

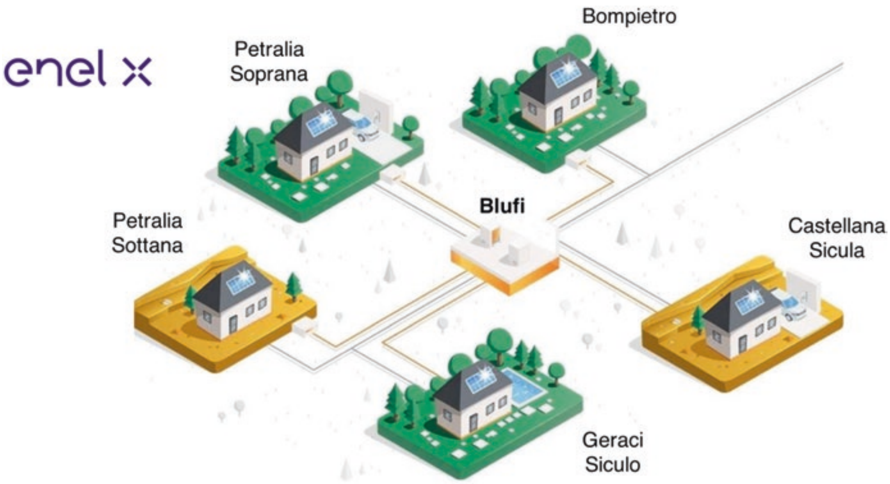

Fig. 3 The energy community of Blufi in the Madonie district. (Author: Luisa Lombardo, 2022)

In so doing, the Blufi Energy Community will contribute to the achievement of the goals that the energy transition imposes at the local level as well. It is a project, in the Madonie municipality, that goes hand in hand with the campaign to raise awareness of green policies that the administration has strongly desired starting with schools. It is no coincidence that it started right there, equipping school roofs with the latest generation of photovoltaic panels, to make the younger generations understand also by example how important it is to produce energy without burning fossil fuels and polluting the atmosphere, but using natural renewable sources such as the sun. Using not only solar panels, but including windy systems, such as the one we have mentioned before, it could be possible to create new energy community that adopt as strategy new technologies without being polluting. What about the other municipalities? Blufi and the other five municipalities are only a quarter of the territory being analyzed to date. Compatible with landscape constraints and the opinion of the Superintendence, one could consider expanding green communities to the remaining part of the territory. This could be an action capable of making such an area smart, as well as representing, on a large scale, a virtuous example on community making in such a vast territory and so rich in resources [14].

6 Conclusions

With these energy examples, especially the virtuous one of the Madonie, we would like, first of all, to improve energy communities in the Sicilian landscape, especially in the Madonie Area, and improve also the connection between these villages where all the built and natural environment take benefits starting from sharing energy. Smart and sustainable development is based on implementing digitalization and useful services to the weakest areas, improving indoor and outdoor comfort, and creating links that contribute to mutual aid companies: a complex of elements coordinated and operating in close union [15]. The challenge and the goal of the research are to revitalize an area that has great potentials, but that it is not yet sufficiently autonomous and it has not yet implemented an energy smart network system [16]. Being a smart community means having a holistic approach and finding multi strategies to enhance the territory. Being an energy community [17] can be the first step in order to achieve the goal of being a smart community or a smart village. Furthermore, the collaboration between public and private institutions leads to the realization of the proposed projects and the creation of guidelines/best practices, to be shared with all municipalities of the territory, are useful to create, devise, and concretize a program of technological development of the "Madonita" area. This system can help exploiting the endemic resources from architectural, social, circular economy and cultural heritage point of view. The final research protocol that is the aim of this research and the identification of best practices are useful to create a program of development and social renewal in this area. Smart identity means also being intelligent involving other entities such as stakeholders, clusters, investors, and local companies guarantee the survival of rural communities and to prepare them for Renaissance. These actions favor not only local culture and traditions, but combining tradition and technological and digital innovation in respecting environment. Furthermore, the scalability of this research represents a chance for sustainable development and a "modus operandi" that can be implemented and transposed in other similar contexts with the same characteristics.

References

1. Barca, F., Carrosio, G., et al. (1989). *Le aree interne da luogo di diseguaglianza ad opportunità per il Paese.* In L. Paolozzi, T. Gargiulo, et al. (Eds.), Aree interne, tutela del territorio e valorizzazione delle risorse. Franco Angeli, ISBN: 9788831797344.
2. Barca, F., Casavola, P., & Lucatelli, S. (a cura di). (2014). *Strategia nazionale per le Aree interne: definizione, obiettivi, strumenti e governance*. Materiali Uval31. http://old2018.agenziacoesione.gov.it/opencms/export/sites/dps/it/documentazione/servizi/materiali_uval/Documenti/MUVAL_31_Aree_interne.pdf (Ultimo accesso 03/11/2020).
3. Boeri, S. (2020). *Via dalle città, nei vecchi borghi c'è il nostro futuro*, la Repubblica, 20 aprile 2020.
4. Cannarozzo, T. (2005). *Centri storici minori e aree interne: verso nuovi distretti culturali.* In AA.VV. (a cura di), Turismo e centri storici nell'Italia contemporanea (pp. 42–53). Tipografia Roncalli.
5. Colajanni, S., Campisi, T., & Lombardo, L. (2021). *I borghi interni in Sicilia: recupero dell'identità e strategie di valorizzazione*, Colloqui.AT.e 2021, Progetto e Costruzione, Tradizione ed innovazione nella pratica dell'architettura.
6. Dalla Torre, R., & Cestari, A. (2018). *La fusione fa la forza. Le aggregazioni tra comuni per lo sviluppo del territorio*. Franco Angeli.
7. El Bassam, N., & Maedgaard, P., (2004). *Integrated renewable energy for rural communities: Planning guidelines, technologies and applications*. Editore Elsevier Science, ISBN: 0444510141.

8. Fantancone, S., & Demostenes, F. (2022). *Crisi o transizione energetica? Come il conflitto in Ucraina cambia la strategia europea per la sostenibilit*à. Editore Diarkos, ISBN: 9788836162024.
9. Fatta, G., Campisi, T., Li Castri, M., Lo Piccolo, S., & Vinci, C. (2007). *La tradizione costruttiva nell'area delle Madonie.* In C. Aymerich, A. C. Dell'Acqua, G. Fatta, P. Pastore, G. Tagliaventi, & L. Zordan L. A cura di (a cura di), Architettura di base (pp. 431–472). Alinea.
10. Lino, B., Contato, A., Ferrante, M., Frazzica, G., Macaluso, L., & SabatinI, F. (2022). *Re-inhabiting inner areas triggering new regeneration trajectories: The case study of Sicani in Sicily.* Sustainability*, 14*, 976.
11. Lombardo, L. (2022). *Patrimonio storico e accessibilità dei centri minori del Parco delle Madonie in Sicilia, in Saperi Territorializzati. Abitare le aree fragili tra accessibilità e consapevolezza.* pp. 62–63, CISAV – Centro Indipendente Studi Alta Valle del Volturno. ISBN: 9791221013436.
12. Martinelli, L. (2020). *L'Italia è bella dentro – Storie di resilienza, innovazione e ritorno nelle aree interne*. Altreconomia, ISBN: 9788865163115.
13. Nicola, L., Lubello, V., & De Luca, A. (2019). *The European Union renewable energy transition*. Editore Cedam, ISBN: 9788813370480.
14. Palazzo, A. L., & Federica B. (2020). *Energy planning in Mediterranean landscapes. Innovation paths in practices and careers*. Editore Quodlibet, ISBN: 9788822905413.
15. Rete giovani ricercatori per le aree interne. (2022). *Le aree interne italiane – Un banco di prova per interpretare e progettare i territori marginali*. Editore List, ISBN: 9788832080681.
16. Steffan, I. T. (2012). *Design for all. Il progetto per tutti*. Maggioli editore, ISBN: 9788838761812.
17. Tricarico, L., Zulianello, M., & De Vidovich, L. (2021). *Community energy map: una ricognizione delle prime esperienze di comunità energetiche rinnovabili*. Editore Franco Angeli, ISBN: 9788835132790.

Environmental Data-Driven Design for the Management of Climate-Adaptive Environmental Design Processes of the Built Environment

Eduardo Bassolino

1 Introduction

The built environment can be seen as a mosaic of shapes and surfaces that determine peculiar spatial morphologies, capable of giving shape to unique environmental conditions. The study of the climate in the city and the repercussions that this brings to the microclimate in the different parts of which they are constituted are decisive in facing the challenge of climate change in progress. Collect and analyze the environmental interactions of the built through the use of advanced and enabling digital technologies, KETs [5], considering the repercussions and the action of the anthropic and the interaction with it [4], allows to decode them with a greater wealth of information [2]. At the same time, the use of digital technologies makes possible to return with less and less uncertainty possible scenarios and strategies capable of containing the impacts of climate change.

The climate crisis scenario that we are facing today inevitably obliges to intervene to avoid making "mistakes," defining approaches and strategies capable of containing the effects deriving from possible inadequacies. This approach is increasingly characterized by interdisciplinarity, as well as by criticalities of the performance of the intervention sites, at the same time holistic, in the ability to consider the dynamic interactions of the built environment (atmosphere, buildings, vegetation, people), but above all capable of returning to objective data on the specific achievable performances.

For this purpose, today more and more Information and Communication Technology tools (ICT) are used for the simulation of the built environment,

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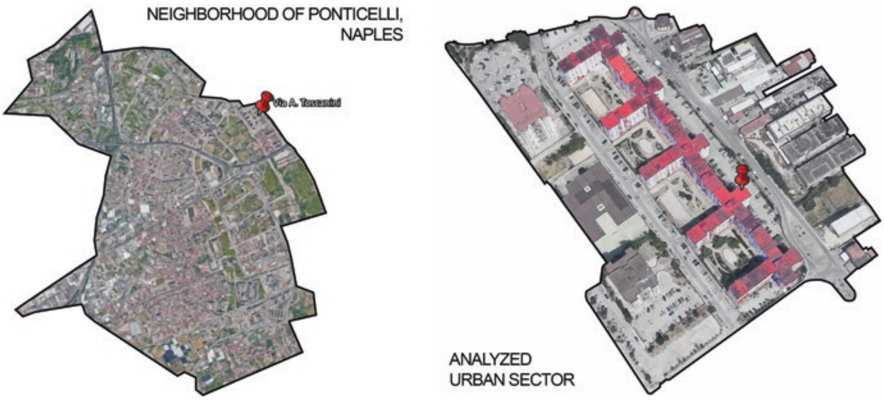
constituting a valid system for the knowledge of the environmental phenomena of the urban space.

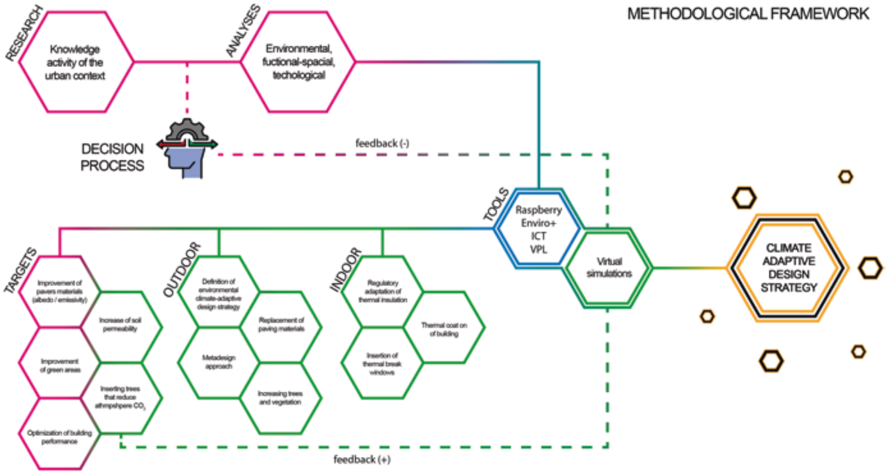
To support the simulation processes, it is necessary to acquire data and information that are useful for the reproducibility of real conditions, such as operations and phases of survey related to the urban shape and geometric data, knowledge of the types of materials of which the surfaces of open spaces are made, but also the construction and performance characteristics of buildings, the types of vegetation and, in particular, the direct and indirect retrieval of environmental and climatic data. Local environmental monitoring actions play a key role not only in defining climatic and microclimatic trends in the urban environment but above all in the construction of databases of information useful in the investigation of the phenomena that most influence the climate in the city, such as the increase in temperatures, the heat island effect and heat waves, constituting databases useful for performing a site-specific "calibration" of IT tools. In this way, the simulation of the state of the places allows for generating "reliable" climatic and microclimatic conditions within the virtual environment, to bring out the technical-performance criticalities of the simulated urban environment, therefore of the real ones.

2 Definition of an Algorithmic Methodological Framework

The processor presented below is aimed at creating a methodological framework based on the use of low technologies for the collection of indoor and outdoor environmental data [6], analytical, simulative and data exchange digital processes. All this is aimed at the knowledge of the systems that regulate the balance of the urban environment in specific contexts, resulting in a fundamental prerequisite to cope climate change in the development of a data-driven approach to environmental design.



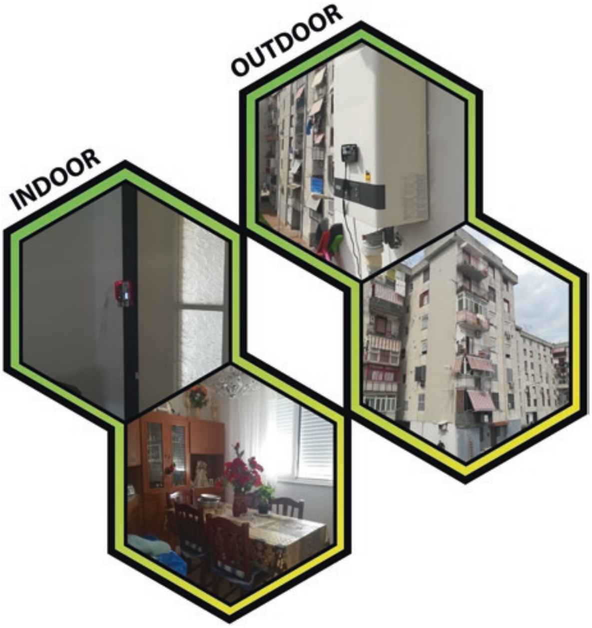
Study context, verification and application is a building sector of economic and popular housing in the Ponticelli district of Naples, built downstream of the PSER—Extraordinary Residential Building Program of 1981.



The methodological framework has been developed through the following phases: (1) the knowledge of the urban, morphological, technological, and environmental analysis context; (2) the direct collection of environmental data through sensors and data on the perception of users' comfort through the submission of an anonymous questionnaire; (3) the construction of an algorithmic process using a VPL platform for the digitization of information and the simulation of indoor and outdoor environmental behavior based on the data collected; (4) the extraction, verification, and validation of the reliability of the results by comparing the data obtained from the simulations with the data obtained from the questionnaires; (5) the definition and application of climate-adaptive regeneration strategies for buildings and open spaces; (6) the comparison of the results obtained before and after intervention.

2.1 *The Investigation Phases*

The collection of environmental and microclimatic data through sensors, the data of the geometric, functional-spatial and technological-constructive characteristics of the urban space, the survey of the materials, and the knowledge of the thermophysical characteristics (thermal transmittance, albedo, emissivity, etc.), as well as the elements of the vegetation, are factors of knowledge necessary for the correct definition of the subsequent phases of simulation within the framework.

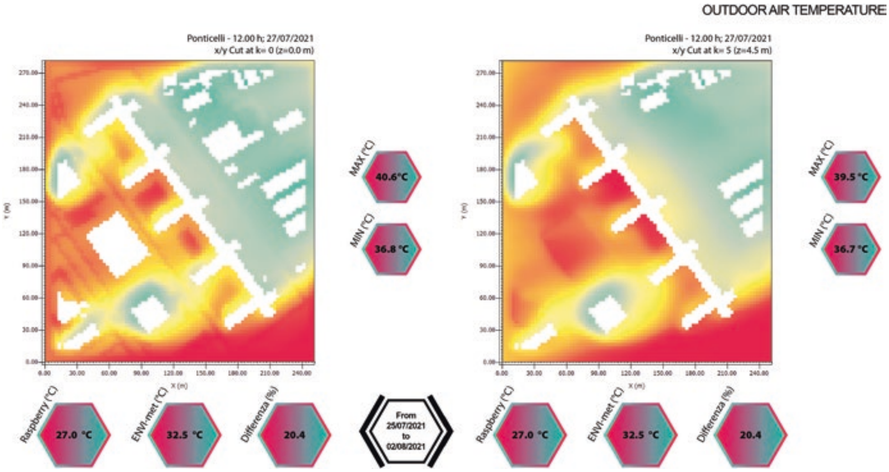


This phase was developed through the use of direct and indirect methods, in a process that is articulated between material and immaterial. In particular, for the survey of indoor and outdoor environmental data, the Pimoroni Enviro and Enviro+ sensors were used, installed on two single-board computers of the Raspberry Pi 4 – Model B type, capable of revealing data on air temperatures, humidity, and solar radiation, while for the construction of virtual models of buildings and open spaces an algorithmic process was used using the Gismo plug-in for the VPL (Virtual Programming Language) platform, Grasshopper, which allowed the execution of a data exchange process of information coming from GIS environment within the Rhinoceros three-dimensional modeling software. A more detailed definition of the model, which includes for open spaces the different surfaces and vegetation present, was obtained through the plug-ins of Grasshopper, *Ladybug* and *Dragonfly Legacy* for outdoor analysis, which allows the connection and exchange of data with the Envimet software, while for indoor analysis, to impute the geometric, constructive, and plant characteristics of the buildings to be analyzed, we chose to use the *Ladybug Tools* suite of plugins, which allow connection with simulation tools such as *Radiance*, *Daysim*, *EnergyPlus,* and *OpenStudio*.

The period of collection of indoor and outdoor environmental data using sensors took place during an extremely hot period for the city of Naples, from 24 July to 02 August 2021. The data obtained were then analyzed to be systematized and converted to use within the algorithmic environment. To do this, starting with a .CSV file, the data has been converted to an. EPW file, which is a standard format for climate data.

2.2 The Development of the Algorithm for the Simulation of Conditions Outdoor

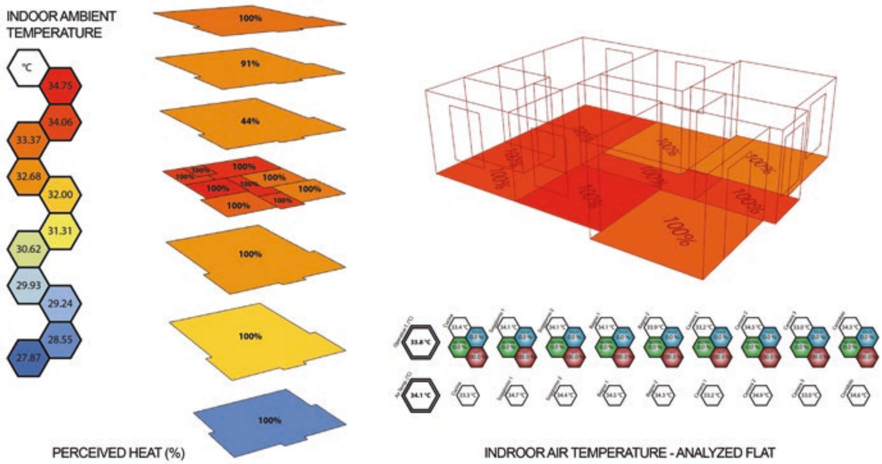
To conduct outdoor simulation analysis of the urban context of reference, extract data and compare them with those obtained from environmental monitoring through sensors, as well as to determine the accuracy of the simulations, an algorithmic process was used based on the Plugins of Grasshopper Ladybug and Dragonfly Legacy, which allow exploiting the simulation engine of the ENVI-met software. Through the assignment in the 3D model of the elements that make up the open space (flooring, vegetation, etc.), the simulation process is started, planning to simulate the same period in which the environmental monitoring took place. Once this phase is completed, the results obtained are compared with the environmental data collected.



The comparison of the average temperature values recorded for the entire monitoring period shows that the way is such a match that it falls within an acceptable difference of 30%, also noting that the software overestimates the daytime data while underestimating the night data.

2.3 The Development of the Algorithm for the Simulation of Door Conditions

A similar procedure has been conducted for data collected indoors. In this case, the algorithm is much more complex than that used for outdoor analysis. Taking advantage of the plug-ins of Grasshopper, Honeybee Energy, and Honeybee Radiance it is possible to define an algorithm that allows obtaining energy analysis of the building, also considering the free thematic contributions coming from solar radiation, in addition to those emitted by the equipment present in the residential units (TV, fridge, air conditioners, lighting, etc.). After setting up the occupancy program of the people inside residential units, the technological characteristics of the building, the control of the openings for natural ventilation, and the possible use of air-conditioning were defined.

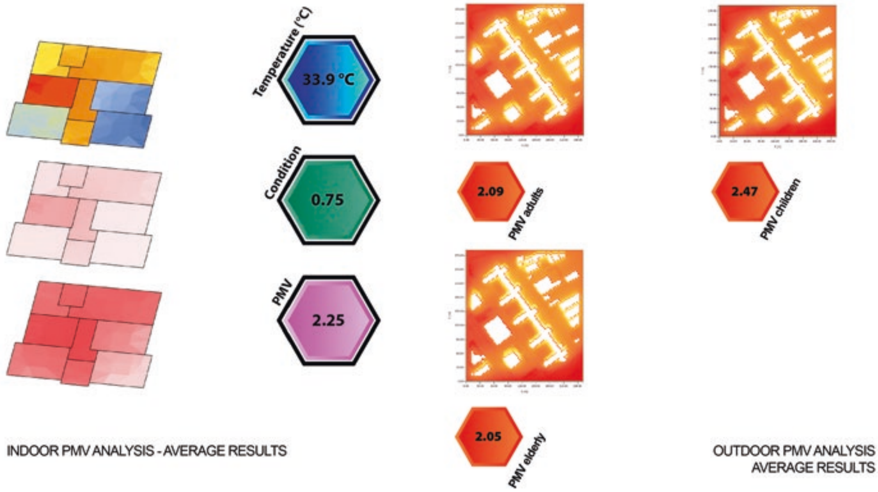


The simulation involves a more detailed analysis inside the apartment where the survey was carried out, while the level of detail is reduced in the apartments in which the internal partitions, equipment, and habits of the occupants are not known. The data was obtained from environmental monitoring and converted into data forms. EPW are imputed inside the algorithm. Once the simulation process is started and finished, the data is extracted and compared with the monitoring data. The average internal temperature simulated is 34.1 °C, which compared with the average temperature recorded by the Raspberry, approx. 31 °C, is kept within a gap considered acceptable.

2.4 *The Analysis of the Perception of Indoor and Outdoor Comfort*

After comparing the environmental data collected through the sensors with those obtained from the simulations, a further step has been to compare the data on the perception of comfort collected using a questionnaire addressed to the users of the housing unit on which the environmental monitoring was carried out. The questionnaire was divided in such a way that each person, day by day, throughout the monitoring period and the four intervals of the day (morning, afternoon, evening, and night) declared the activity he carried out, specified the clothing worn, and noted his thermal perception inside and outside the apartment.

For this purpose, and from the algorithmic simulation processes, data have been extracted for both outdoor and indoor simulations, according to the index of PMV—Predicted Mean Vote [1, 3, 8], which measures the feeling of comfort perceived by a user according to a scale ranging from −3, very cold, to +3, very hot, and where the feeling of comfort is expressed in the range from −1 to +1.



The comparison of these results confirmed how much the thermal sensation perceived in the reference period by the different categories of users, such as adults, the elderly, and children, stands on a feeling of heat or very hot, both indoors with average values of 2.25 and outdoors with average values of 2.11.

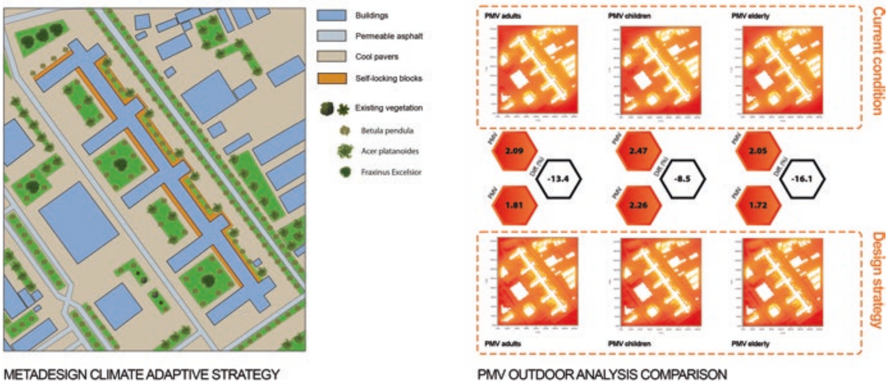
3 Results

Following the analysis operations, comparison, and then verification of the reliability of the developed algorithmic framework, a design process was conducted following a meta-design approach of the redevelopment of open spaces through climate-adaptive design strategies, as well as a hypothesis of technological and energy retrofit of the analyzed building.

In addition, a further analysis process was carried out to verify how much the redevelopment of open spaces impacted the energy behavior and the perception of comfort within the environments of the building subjected to intervention of retrofit.

3.1 The Climate-Adaptive Strategy for the Redevelopment of Open Space

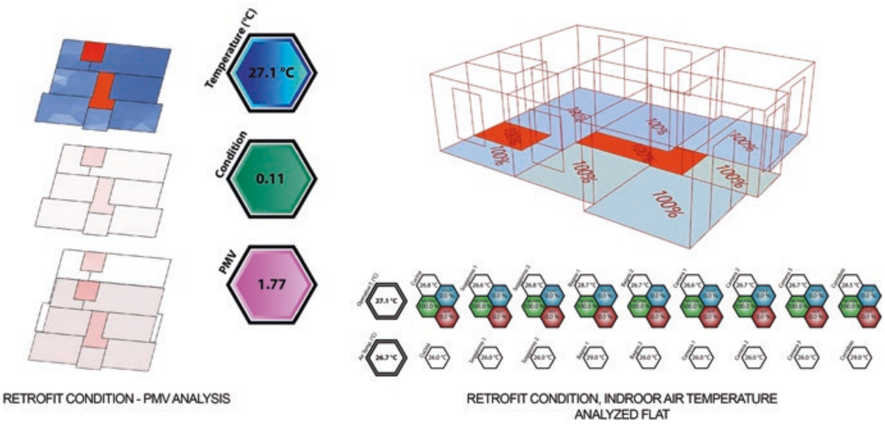
The urban regeneration phase was carried out according to a meta-design strategy that would put in place categories of intervention of climate-adaptive design solutions, providing, for instance, the insertion of new vegetation (trees, green surfaces, etc.) and the provision of cool material for the pavements.



The values of the air temperatures obtained from the simulations that involve redevelopment interventions, and compared with the actual condition, give back an average reduction of 2.79%, with an average air temperature of 31.5 °C. Similarly, the external PMV values of adults, children, and the elderly tend to improve, recording values between fairly hot and hot.

3.2 The Performance Adaptation of the Building for the Improvement of Indoor Environmental Conditions

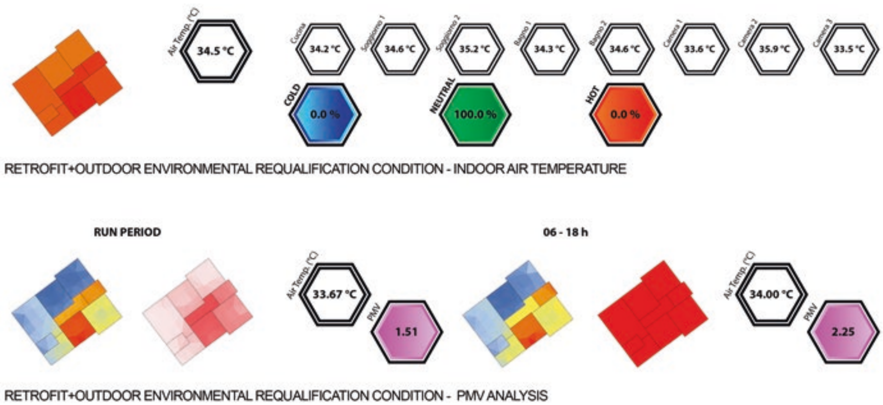
For the technological and energy retrofit of the building, to comply with the minimum requirements provided for by national legislation in the D.M. June 26, 2015, it is planned to intervene on the entire envelope by affixing a thermal coat, providing rock wool panels, with the addition of a layer of clay on the roof and, to the intrados of the same, the insertion of sheets of fiberglass. For transparent closures, PVC thermal break windows have been provided.



The results obtained show that both the average internal temperatures of 27.1 °C, with an average reduction of 20%, and the feeling of comfort of the PMV values that stand at 1.77, with an average reduction of 21.8%, define a decidedly improving condition.

3.3 The Combination of Indoor and Outdoor Strategies

Finally, it has been verified how the building that has undergone retrofit action would have reacted in the condition of the redevelopment of open spaces, making the environmental data extracted from the simulation process in which the hypothesized climate-adaptive design actions acted within the algorithm.



In the design condition, in the absence of controlled mechanical ventilation, only with natural ventilation, the average indoor temperatures remain unchanged compared to the starting condition, while the PMV values present a hot condition with average values during the entire monitoring period of 1.51.

4 Conclusion

The use of different forms and uses of digital technologies can feed the vision of sustainable development and climate-oriented cities, based on a data-driven approach, in which data can serve as an interface between the desired objectives and the progress achieved [7].

KETs, big data, simulations, analysis and models of predictive scenarios, represent in their heterogeneity a set of tools useful for the construction of a "new" working environment for environmental design, which shifts its center of gravity toward the governance of processes and the definition of the project and its specific solutions.

Today, through tools capable of quantifying in a preventive way the effectiveness of transformation interventions and the comparison with real data and feedback from citizens, through data processing processes between material and immaterial, it is possible to configure and use data exchange and interoperability environments in which recursive processes allow to synthesize the instances of the project with the most adequate performance obtainable.

The framework developed, although implementable, represents the starting point for the creation of an open-source database capable of containing different information and instances concerning urban areas to be redeveloped, proposing itself as a matrix of typological case studies for the application of environmental and climate redevelopment strategies.

References

1. ASHRARE. (2020). *Standard 55 – Thermal environmental conditions for human occupancy*. ANSI/ASHRAE, Peachtree Corners.
2. Bibri, S. E. (2021). Data-driven smart sustainable cities of the future: An evidence synthesis approach to a comprehensive state-of-the-art literature review. *Sustainable Futures*, Vol. 3, Elsevier, 100047. https://doi.org/10.1016/j.sftr.2021.100047
3. Fanger, P. O. (1972). *Thermal Comfort – Analysis and Application in Environmental Engineering*. McGraw-Hill Book Company.
4. Giffinger, R., & Lü, H. (2015). *The Smart City perspective. A necessary change from technical to urban innovation*. Fondazione Giangiacomo Feltrinelli.
5. Governo Italiano. (2021). Piano Nazionale di Ripresa e Resilienza, Roma. https://www.governo.it/sites/governo.it/files/PNRR.pdf
6. Marrone, P., Orsini, F., & Raimondi, A. (2020). Scenari e tecnologie a basso costo per la rigenerazione ambientale degli spazi tra le case. In M. Perriccioli, M. Rigillo, S. Russo Ermolli, & F. Tucci (Eds.), *Design in the digital age. Technology nature culture*. Maggioli Editore.
7. Ratti, C. (2021). How the data revolution will help the world fight climate change. foreignpolicy.com. https://foreignpolicy.com/2021/10/20/climate-change-cities-big-data-artificial-intelligence/?utm_campaign=clipping_institucional_dia_a_dia&utm_medium=email&utm_source=RD+Station
8. UNI - Ente Italiano di Normazione. (2006). UNI-EN-ISO 7730:2006 – Ambienti termici moderati – Determinazione degli indici PMV e PPD e specifica delle condizioni di ben.

Energy, Resource Circularity, and Retrofitting in Positive Energy Districts

Federica Nava, Maria Michaela Pani, and Violetta Tulelli

1 Introduction

Today the world population has reached 7.9 billion people, and it is estimated that this number will exponentially grow over the next few decades to reach 9.7 billion in 2050 [1]. In a so densely populated world, with a limited amount of resources and hit by the climate crisis, pursuing a model of sustainable development cannot be considered an optional solution.

According to "The net- Zero Carbon Cities Building Value Framework," more than half of the world's population currently lives in cities [2]. Therefore, although cities occupy only 3% of the Earth's surface, they are responsible for 60–80% of energy consumption and 75% of carbon emissions [3]. In particular, buildings are responsible for over 38% of global CO2 emissions, which is why implementing concrete and massive actions for an environmental and sustainable design has a primary importance.

2 Adaptation and Mitigation

It is well known that adaptation, defined as adjustment to the current and future effects of climate change, indicates fundamental guidelines for combating natural phenomena that unfortunately we are experiencing more and more frequently and intensely in recent decades. Phenomena such as drought, heat island, and excessive

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summer temperatures, followed by sudden and violent storms and “water bombs” in winter and also more extreme phenomena such as landslides and earthquakes, have become progressively frequent in Europe. It is observed a 1.5 °C increase in average temperatures from the pre-industrial era, accompanied by a 10–30% increase in extreme summer phenomena, such as the increase of water scarcity and the increase of sea level of about 2.8 mm per year [4].

For this reason, it is important to act in a synergic way, both in the context of adaptation and in climate changes mitigation, i.e., the set of strategies adopted to reduce the causes of climate change, ambit in which issues relating to circularity of resources (smart and ecological systems for water management, solid urban waste and various types of waste), the production of clean energy and urban retrofitting converge and intertwine each other.

3 Circularity

As already mentioned, the exponential increase in recent decades of the world population and its growing urbanization lead to the necessity of paying more attention about the circular economy principles: the reduction of the use of resources, materials and energy, and the decrease in waste production and scraps [5]. The corollary of this condition is self-sufficiency (i.e., the achievement of well-being conditions and autonomy without depending on raw materials or external help) thanks to the production of resources, materials and energy as much as possible on site.

In addition to the question of the scarcity of resources, many studies underline the importance of the contribution of the circular economy to the abatement of greenhouse gas emissions, which is why a challenging target of greenhouse gas reduction by 2030 (reduction of at least 55% of CO_2 compared to 1990 levels), has been set by the European Green Deal and the SDGs of the 2030 Agenda. Achieving this target necessarily requires significant measures to reduce the circularity gaps. The scientific community agrees that doubling the current circularity rate would cut about 22.8 billion tons of greenhouse gas emissions globally [6].

Investigating the path of different flows of resources, divided into “materials” (gray water, wastewater, organic waste, urban solid waste, construction processing waste…) and “intangible” (energy, heat or waste heat, gas…), the theme of circularity is strictly linked to energy production, storage and reuse.

4 Energy

Energy consumption is responsible for about 75% of GHG emissions in the European Union. The electrification of consumption, which should encourage the transition to renewable energy sources, is increasing the demand for electricity, too. However, data at the moment is not comforting: in Italy, for instance, the energy sector still uses 80% of fossil fuels, and only 19% of renewable sources; moreover, it represents a fixed value in the last five years [7].

The building sector is one of the most energy-hungry and requires a strong transformative action at different scales, including both single building and urban district, increasing the use of renewable sources, energy efficiency, low-emission technologies and integrated energy systems [8]. For this reason cities, and specifically buildings, have a significant role in the ecological transition [9] and require actions and new solutions to improve life in urbanized areas [10], implementing network flexibility and efficiency, bringing the goal of near zero energy external demand from the building scale to the district scale.

The close connection between energy issues and the reduction of climate-altering emissions, especially CO_2, underlines the need to bring attention to a circular, efficient, and effective management of energy resources, implementing grid flexibility, decentralizing energy systems, and spreading them into cohesive local systems, aiming at the reduction of energy imports and CO_2 emissions [11].

5 Retrofitting

In terms of availability of housing, Italy has one of the highest numbers of buildings available [12]. However, experts estimate that over 1.2 million of new buildings are going to be built in the next ten years, beyond the necessary for the Italian scenario, which has a constant decrease of demography. It is necessary to act on the existing heritage in a double way: on one hand considering the heritage as a resource and not as a waste that need just to demolished and rebuilt (action that would have a significant impact on embedded carbon emissions) and, on the other hand, from a green viewpoint concerning the alarming global climate situation. In this sense the instruments available are varied and include certifications and protocols, such as GHG INVENTORY TOOL, and energy certifications, such as LEED historic building and Passivhaus standard. In addition, the combined use of instrumentation aimed to purely restore and maintain with ones that are focused on consolidation, such as the Technical Standards of buildings 2018, ensures the stability of buildings in front of the increasingly frequent extreme phenomena due to climate change.

By ensuring good bioclimatic behavior and using renewable energy sources, it is possible to achieve good levels of energy saving and reduction in emissions. Referring to the actual energy crisis, the simultaneous use of these strategies is indispensable, as well as part of the 17 objectives of the 2030 agenda: "the path toward a low-carbon economy requires the transition from a high intensity production energy system to a new model of economic development based on energy saving and the diversification of sources, in a context of a broader cultural, behavioral and technological transformation."

6 PEDS: Positive Energy Districts

In the context of urban regeneration projects, it is important to identify the right scale of intervention, which brings individual benefits and, at the same time, contributes to collective well-being in terms of environmental sustainability. The energetic and ecological requalification of a single building is not much significant in the overall budget of a city in terms of emissions reductions. At the same time, thinking of redesigning an entire city could be considered an unrealistic and complex approach.

The most feasible solution, as it is easy to imagine, operates at an intermediate level: to some extent, eco-districts are small-scale Smart Cities, in which it is easier to develop the project, monitor its developments and manage flows and connections between the different components that make up the neighborhood. This strategy represents an excellent opportunity to experiment, with new strategies and urban models, our cities' transformations into more sustainable and livable ones.

Furthermore, at the neighborhood scale it is possible to redevelop or rebuild individual buildings, but also to promote the establishment of sustainable services and communities so-called "smart communities" [13].

Fortunately, there are now numerous examples of Positive Energy Districts around the world, thanks to programs funded by Horizon Europe such as SPARCS + Cityxchange and Making City, with the ambitious goal to create 100 PEDs by 2025. Among these, we have selected three of the most interesting and representative cases in Mediterranean countries (Spain, Italy and France) for which we compared, in particular, three thematic axes: bioclimatic, energy, and resources circularity.

7 Ecobarrio De Trinitat Nova, Barcelona, Spain

Trinitat Nova is located in the northern part of Barcelona and it belongs to the Municipal District of Nou Barris. It is based on the southern slope of the Sierra de Collserola and it is bordered by two large traces of the territory: the Avenida de La Meridiana and Ronda de Dalt, which physically separate it from other neighborhoods. The neighborhood was built in the decade of 1950 to solve the social housing problem. In 1953, the construction of Trinitat began and most of the buildings were built without the presence of projects. The area lacked the minimum equipment (roads, infrastructures). The houses were small (the majority did not reach 50 square meters) and made of poor-quality materials. The physical decay of the neighborhood started almost from the moment of its completion. The neighborhood did not offer any service or specific facility. From a socioeconomic point of view, people that live in the area have a low education and a high incidence of unemployment rate, compared to other districts of Barcelona. Finally, the presence of an aluminosis problem led to the development of a programmatic document, which, by establishing a priority intervention area, pushed to requalification actions. In the area there are four types of blocks, for a total of 891 dwellings.

Various points have been considered in the transformation of Trinitat Nova into an eco-district. In the past, the water loss factor was estimated at 7.8%. The district's regeneration plan provides the reparation of drinkable water pipes, which do not need major maintenance. The solutions proposed for the reuse of water for domestic use are: the installation of water pressure reduction devices compliant with the legislation, the optimization of the section of the water pipes according to the number of inhabitants per single home, the design of DHW systems: generally a short piping system guarantees less waste of heat, correct insulation of the pipes, the presence of a centralized DHW production system. For the urban environment, the solutions proposed are: the application of permeable surfaces for car parks or emergency accesses, the evaluation of the possibility of creating green roofs or, alternatively, the collection of water rain from the roofs, the study of atmospheric polluting factors, such as heavy metals, the maintenance of the natural filtration of the soils of the area adjacent to the water table. Assessments of the filtration capacity of basins and streams, assessments on the naturalization capacity of old wetlands and on the use of collected water were necessary for the quantization and sizing of the retention, accumulation, filtration systems and the application of filter blocks underground. This allowed the collection of up to 20 tons of water, thus increasing the volume of water by approximately 96% of its total volume (950 liters per cubic meter).

Recovery of biodegradable waste through the production of compost, methane and biogas. This gas can be used as an energy source for high performance boilers. The production of biogas varies between 130 and 160 m^3/tons of waste depending on the type. The environmental advantages, compared to composting, pass through a lower CO_2 emission and include livestock waste, sludge from treatment plants (WWTP), effluents, industrial waste, and the organic fraction of municipal solid waste. The methanization of organic matter is the process of recycling or using waste to generate biogas, which is then used for energy production.

The installation of a combined system for heating and domestic hot water supply enabled a reduction of 45% of primary energy and CO_2. The cogeneration of heat and electricity allows a further reduction in consumption of 30%.

The solar thermal appliances installed vary from minimum mandatory systems such as EE-130 ACS, which supply 150 kW per building type, to E-E systems which supply the building type 200 kW. Other air systems are present, such as the E-I and E-X systems that cover 225 m^2 and 2925 m^2, respectively (i.e., 325 m^2 for a typical building). Finally, systems such as EBX-S and EBX-CS were also installed for a total collection area of 1575 m^2 (175 m^2 for a typical building) and 2025 m^2 (225 m^2 for a typical building).

Heat Energy saving is also guaranteed by the presence of boilers with a cogeneration power of 150 kWt for a 300kWt boiler.

Photovoltaic panels are installed throughout the neighborhood. Considering, for the city of Barcelona, an annual yield for a photovoltaic panel of 10% and an annual solar production of a device that is around 1.3 kWhe/Wp, with 125 Wp/m^2, the annual savings in emissions of CO_2 is 623 Kg CO_2eq/kWp. Following a study on what measure could guarantee greater efficiency for the city's climate, small independent appliances with a power of 5 kWp inclined at 30/35 degrees, orientated on south, were set up.

A bioclimatic design on the existing buildings allowed further energy savings and minimization of the waste resources. Systems such as water-saving plumbing systems for dual-flow faucets and toilet drains. These installations, despite being very cheap, have allowed significant savings. The collection and reuse of water from showers, bathtubs, bidets, sinks and washing machines is another strong point for Trinitat. In particular, a LOKUS submersible rotating body type system was used. The elements that make up the system are gray water collection system, treatment system, and sanitation system. The selected plant is semi-centralized, with a treatment plant for every two residential blocks, producing an amount of 10,000 liters per day for every 150–200 people.

Finally Trombe walls, face change materials, solar accumulation systems and double-glass windows have been installed. The good facades' orientation helps to reduce the energy use. Finally the cross ventilation reduces 43% of cooling demand [14].

8 Casanova, Bolzano, Italy

In 2002, the Municipality of Bolzano, a city that has always paid attention to sustainability and clean energy, bought 10 ha of agricultural land in the locality of Bivio-Kaiserau and planned the Casanova neighborhood with the intention of satisfying the need for social houses.

The settlement consists of eight open-type and irregularly shaped residential courtyards, in which have been built 941 apartments, hosting about 3500 people. A public space located in the center of the district hosts mixed residential, commercial functions and facilities.

The architectural project interprets the settlement theme of the "castle," a residential nucleus formed by three or four imposing buildings gathered around a small green courtyard, starting from three elements that characterize it: the fence that defines and delimits the block, the massive envelope that expresses the character of the block, and the court that represents its heart. Architecturally, the desire to accentuate the unity of the project leads to identify a single compositional register of the facade and this characteristic is expressed with different opening solutions for the internal elevations, with large loggias toward the courtyard space compared to the external elevations, underlining the different nature and value of the view.

The integration between the intervention area and the city center was achieved through cycle-pedestrian routes and public transport lines, thus helping to discourage the use of cars. The project area involves the presence of the railway line, a strong element of recognition and a fundamental hub for the mobility of the whole area, thanks to which the public transport system is further strengthened.

The energy sustainability of the neighborhood is certainly the aspect on which the most effort has been devoted. The energy policy was "to produce better and consume better," a phrase that is often heard, which was then found to be concretely implemented with Casanova.

In 2003, the limits for energy needs for heating were set nationally at about 90 $kWh/m^2/yr$. (Italian Law 10/91). On the other hand, for the district it was decided to impose stricter limits also taking into account the size of the buildings: for residential buildings smaller than 5000 m^3 the limit is 50 kWh/m^2a (CasaClima class B), for larger buildings of 20,000 m^3 is 30 $kWh/m^2/yr$. (CasaClima class A), for buildings between 5000 m^3 and 20,000 m^3 in volume the limit varies linearly (CasaClima A parameterized). A larger building, in fact, is intrinsically more virtuous since the ratio between the dispersing surface and the volume of the building decreases. For buildings with other intended use (buildings for the tertiary sector, schools, sports, …) compliance with class A is required, regardless of the volume. With these innovative solutions it has been possible to achieve an annual energy savings of 42% compared to traditional buildings.

With the aim of reducing consumption or "consuming better," dispersion is reduced for all buildings by adopting high insulation values and choosing a compact and regular shape. They are equipped with green roofs, with massive walls (that means high thermal mass), well insulated and with glass surfaces of different sizes depending on the orientation of the facades.

The optimization of solar gains was achieved by varying the height of the buildings, whose decreasing heights toward the south favor natural lighting and radiation, as well as shielding from cold winter winds and channeling summer ones.

As far as "producing better" is concerned, the "castles" are equipped with renewable energy systems: solar and geothermal.

Solar energy is exploited for the production of thermal energy through solar thermal collectors that provide the needs of about 35% of domestic hot water, and for the production of electricity through photovoltaic panels which, with an average capacity per accommodation of about 250 W at peak, contribute to the electricity needs with a global production of 260.000 kWh/yr. [15].

Geothermal energy is used both as an integration to the heating needs and as a cooling system through a water circuit, and as preheating and precooling of the ventilation air of a castle through an air circuit.

For the production and distribution of thermal energy, a district heating system was built, with which it was possible to achieve savings in annual energy requirements of 31% compared to a solution with autonomous boiler systems for each residential unit. This innovative solution has numerous advantages: firstly, the control of polluting emissions which are concentrated in a single point to allow constant maintenance of the minimum values and continuous control over the type and quantity of emissions; secondarily, the possibility of accounting for thermal energy to record the energy consumption of each individual accommodation and dividing the costs based on actual consumption; furthermore, district heating allows for less overall losses and; finally, it becomes possible to recover the heat produced by the nearby Bolzano incinerator (as if it were a large boiler that heats the buildings), which would otherwise be dispersed into the environment, and now redirect it into the district heating network.

A district cooling system also serves the district's tertiary users. A power plant powered by the district heating network located in a barycentric position produces chilled water thanks to absorption machines. In this way, the heat recovery from the incinerator will always be active: in winter for heating and the production of domestic hot water, in summer for the production of domestic hot water and for powering the absorbers.

At the plant level, measures have been adopted to reduce energy consumption such as district heating, geothermal heat pumps, radiant panel heating and cooling, and a controlled ventilation system with heat recovery.

The new district also provides innovative measures for the distribution of drinking water and gas for domestic use, for the disposal of black water, for the distribution of electricity and for the disposal of white water, both public and private, collected in cisterns or tanks, and subsequently used for irrigation and for the conservation of large surfaces permeable to green and for the formation of a humid area along the railway, capable of producing favorable effects on the microclimate.

The rainwater precipitated on the surfaces of the main roads is conveyed into drainage wells and depressions that spread the water underground. The excess water, which the wells and depressions are unable to disperse, is conveyed through a general drainage network to a central pumping station and then fed through a pressurized pipeline into the Isarco River.

The rainwater that has fallen on the surfaces of secondary roads and on the roofs of buildings, and therefore is "cleaner" than the former, is instead conveyed through storm water collection systems to collection and sedimentation tanks and is used for the irrigation of public green areas.

Each "castle" is equipped with a cistern for the accumulation of rainwater collected from the roofs of the buildings, with a capacity of 20,000 liters.

9 Grenoble-Alpes Métropole, Grenoble, France

Grenoble-Alpes Métropole is the first French city to adopt a Climate Plan in 2005. This program was full of initiatives, designed to combat climate change. Soon this Plan morphed into an Air Energy Climate Plan, which sets, among others, specific objectives in terms of greenhouse gasses and principal pollutants, as well as the use of renewable energy. In the period between 2005 and 2010, energy consumption decreased by 5.4%, greenhouse gas emissions were reduced by 18%. Final energy consumption per inhabitant in 2011 was 19.7 MWh.

To take the commitment toward the ecological transition to the next step, Grenoble joined, as a demonstration city, the project City-zen [16]. This program was granted EU-funding "to develop and demonstrate energy efficient cities and to build a methodology and tools for cities, industries and citizens to reach the 2020 targets." The program, rooted in Amsterdam (NL) and Grenoble (FR), had its first official kick-off in March 2014.

The municipality has launched the Éco-cité project in the northern part of the city, bringing together public and private stakeholders around demonstration projects mainly concerning mobility, energy retrofitting of existing buildings and renewable and recovered energy. The overall Grenoble objective of the City-zen project was to transform the Éco-cité area into a positive energy and carbon neutral district.

The reduction of energy consumption is fundamental to support the energy transition, Grenoble-Alpes Métropole has strategies that aim to: energy sufficiency (to reduce wasteful need and loss) energy efficiency (aiming to use less energy to achieve the same result) and thermal renovation of buildings envelops. In fact, 42% of total energy costs is attributed to buildings and they waste a lot of energy due to a bad management of their design and needs: overheated offices, badly insulated housing, poorly designed public facilities, etc. Grenoble-Alpes Métropole is strongly committed to the thermal renovation of public and private buildings built between 1945 and 1970, not only those intended for residential use (social housing and private property) but also office buildings, stores, universities, and hospitals.

The first action taken in this direction is investing in insulating residential buildings: between 2010 and 2015, 5000 private and 5000 social housing units were renovated. Grenoble-Alpes Métropole wants to further extend this policy and, to achieve the aim of a 19% reduction in household consumption by 2030, it needs to double the number of annual renovations. To reach this target City-zen collaborates with several stakeholders, ALEC for the public building, and the Mur|Mur program for insulating buildings. It has already seen the thermal renovation of 5000 private apartments and it has been extended in 2016. Its successor Mur|Mur 2, with the objective of 10,000 extra housing units renovated by 2023, offers a wide range of support and solutions depending on type of housing, household income and level of renovation.

Furthermore, a web platform will be implemented to provide day-to-day access to gas, electricity, and heating consumption data. The data will be compared to the consumption of equivalent houses and flats, allowing the citizens to monitor their own behavior, providing advice and tips to improve the performance and to increase the awareness.

Grenoble-Alpes Métropole aims to change the energy mix, increasing the share of renewable and recovered energy by 35% and reducing the use of fossil fuels by 30%. In the future, heating systems will use more and more renewable energy with the construction of new wood-fired boilers and the use of solar thermal or geothermal energy for heating and cooling. The main heating system will increasingly use wood and recovered heat produced during the industrial process and recovered as an energy resource.

Grenoble-Alpes Métropole will also extend its biogas production, encourage photovoltaic electricity and exploit the full potential of hydroelectricity.

The new biomass power plant, called Biomax, will soon replace an old fuel oil boiler, and two power plants will be modified by 2025, permanently eliminating coal, powering four new district heating networks by 2030. In parallel, the excess heat produced on the Pont-de-Claix chemical platform will be recovered and feed this network. This solution compensates for the expected decrease in heat resulting from waste incineration. The amount of waste incinerated is set to decrease as a large amount has to be sent for recycling, as set out in the new waste action plan.

Since 2016, the local Aquapole treatment plant has been equipped with a biogas production unit, fed with sewage sludge, which generates 20 million kWh, the equivalent of the energy consumption of 2500 families.

By 2025, Grenoble-Alpes Métropole will create a second biogas production unit using food waste that will soon be collected throughout Grenoble in accordance with the new master plan on waste.

To obtain the benefit from this action, also the distribution network must be optimized to be capable to sustain and distribute a higher load coming from renewable energies and to meet the needs of electrification. It needs an optimized control and dynamic management of energy flows, innovative storage solutions and interconnectivity.

The key-action in the Roadmap of Grenoble Éco-cité is the synergic collaboration of local authorities, research and innovation stakeholders, partner associations and citizens to draw up the Energy Master Plan. Connecting people and districts of the city, planning actions in a timeline, empowering citizens in the process boost the shared vision for the future. The results in achieving climate neutrality, realizing a sustainable metropolitan region, are remarkable: CO_2 emission reduction 10900tCO_2/year, Primary energy saving 48,444 MWh/year Final energy saving 35,621 MWh/year.

Grenoble is the European Green Capital of 2022 for its commitment to go further and for everyone in the public and private sectors, nonprofit organizations and residents to look to 2030 together and make Grenoble a city that is more resilient, welcoming and united.

10 Conclusion

The research leads to a methodological tool that can be replicated for other case studies, looking to future investigations and methodology developments.

The first step consists in a comparative table, in which it is possible to highlight every technological solution belonging to each subcategory of the three macro-areas selected (circularity, energy, retrofitting/envelope). Comparing the results, it is possible to understand differences and analogies between the different districts analyzed.

			SPAIN	ITALY	FRANCE
	TYPE OF ENERGY PRODUCED:				
ENERGY	Thermal energy production	Solar thermal collector	☑	☑	☑
		Cogeneration	☑	☐	☐
		Biomass and wood-fire boilers	☑	☐	☑
	Electricity production	Photovoltaic panels	☑	☑	☑
		Hydro-electricity	☐	☐	☑
	Geothermal energy production	Geothermal heat pump	☐	☑	☑
	Heat storage	Heat storage PCM	☐	☐	☑
	Heating production	District heating system	☐	☑	☑
	Smart management	Smart management	☑	☐	☑
CIRCULARITY	Water	Recovery of rainwater	☑	☑	☐
		Recovery of domestic water	☑	☐	☐
	Heat recovery	Heat recovery from incinerator/industries	☐	☑	☑
	Energy from waste	Biogas from waste/seawage sludge	☑	☑	☑
	Smart management	Smart management	☑	☐	☑
RETROFITTING AND PASSIVE TECHNOLOGIES	Envelope		retrofitting	new building	retrofitting
		Ventilated facades and massive walls	☑	☑	☐
		External insulation	☑	☑	☑
		Window replacement	☑	☑	☑
		Green\blue roofs	☑	☑	☐
	Systems	Reparation and optimization of old systems	☑	☐	☑
	Smart management	Controlled ventilation	☐	☑	☐
		Improving inhabitant behaviour	☑	☐	☑

Fig. 1 Comparison between different PED's strategies (authors elaboration)

The three districts largely use sun as a major renewable energy source, adopting photovoltaic and solar thermal systems. Geothermal and hydroelectric energy, on the other hand, are not always used and wind energy was not designed. This choice probably is due to the geographical area and the latitudes in which the districts fall: the Mediterranean climate is characterized by a high percentage of sunny days with no wind per year.

Regarding circularity, the use of waste as an energy resource, especially to produce biogas, is positively underlined. Waste is a secure source of energy supply, significantly contributing to the energy mix and increasing the resilience of grids.

In terms of retrofitting and passive technologies, there are some macro actions in common even if they are applied in different ways depending on the type of project (retrofitting or new construction) (Fig. 1).

Starting from the table it was possible to extrapolate the data into three radar graphs, showing the percentage of action undertaken for each subcategory. The radar charts visually show differences and similarities between the ecodistricts, strengths and aspects that need further implementation.

In conclusion, we can say that the eco-districts selected for their commitment to decarbonization and climate adaptation and mitigation, although they belong to the Mediterranean area, present different applications of the solutions adopted, based on their own regulations and rules dictated by the climate and the local context (Fig. 2).

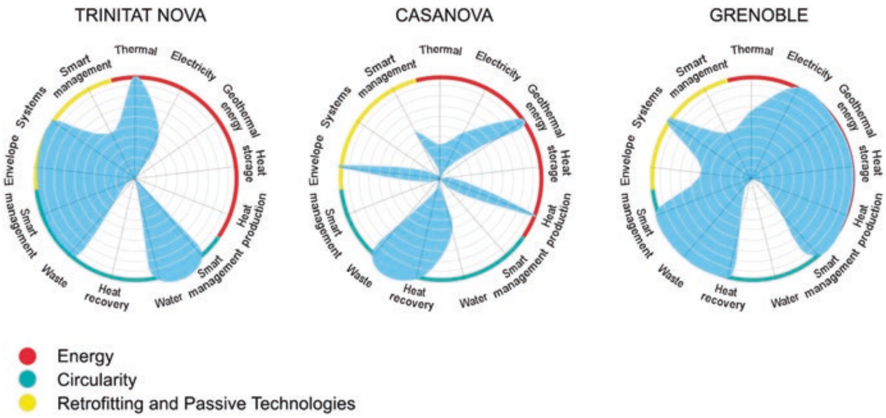

Fig. 2 Strategies radar scheme (authors elaboration)

References

1. United Nations. (2019). World Population Prospects 2019: Highlights, p. 5.
2. World Economic Forum. (2022). Accelerating the decarbonization of buildings: The net-zero carbon cities building value framework, p.3.
3. European Environmental Agency. (2020). *Air quality in Europe – 2020 report*, p. 12.
4. Mediterranean Experts on Climate and Environmental Change (MedECC). (2020). First Mediterranean Assessment Report Climate and Environmental Change, Mediterranean basin, Current situation and risks for the future, p. 3.
5. Circular Economy Network (CEN). (2022). 4° RAPPORTO SULL'ECONOMIA CIRCOLARE IN ITALIA, pp. 7–13.
6. https://ellenmacarthurfoundation.org/circular-examples/the-eus-circular-economy-action-plan, consulted on 16/July/2022.
7. Italy 4 Climate. (2021). La Roadmap per la neutralità climatica dell'Italia, p. 6.
8. United Nations. (2018). *The Sustainable Development Goals Report 2028*, pp. 7, 22, 23.
9. International Energy Agency (IEA). (2019). *Empowering cities for a net zero future*, p. 9.
10. Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate change, mitigation of climate change*, pp. 40, 53, 56.
11. European Commission. (2018). Annual activity report, *Joint Research Center,* pp. 20–21.
12. Housing Europe. (2021). The State of housing in Europe, p. 75.
13. Legambiente. (2013). Comuni rinnovabili, pp. 23–24.
14. Gea21. (2004). ECOBARRIO DE TRINITAT NOVA, Propuestas de sostenibilidad urbana, Documento de síntesis de los estudios sectoriales de sostenibilidad, pp. 24–26, 33, 101, 231–237, 346–256, 269–277, 307, 311–313.
15. Eurac Research. (2013). CasaNova. Nuova concezione sostenibile dell'abitare.
16. http://www.cityzen-smartcity.eu, consulted on 16/July/2022.

An Urban Infrastructure as Quality City Connector in a Multistakeholder Approach

Luciana Mastrolonardo

1 Introduction

The achievement of sustainable mobility target, within the European objectives as the Green Deals [1], is strongly integrated with the Ecological Transition. By fostering innovation and transformation, programs support the vision of creating more livable urban spaces because Europe wants to improve people's quality of life, decarbonize mobility, and make Europe's economy more competitive through New European Bauhaus [2], an environmental, economic, and cultural project, which aims to combine design, sustainability, and accessibility and connects the European Green Deal to our living spaces and experiences.

At a European level, the systemic approach to sustainable mobility is becoming increasingly important, so cycling is no longer a matter of transport, but of energy efficiency and the fight against climate change: cycling has always been considered a part of the complex transport system. Today, after the pandemic that taught us that it is possible to move on a small scale (this is why we are talking about the city of 15 minutes), the bicycle has become an indispensable part of the process of combating climate change. In the context of energy scarcity contextual to the war in Ukraine, the bicycle represents, for the most enlightened governments, the tool from which to start to contain the consumption of hydrocarbons. By reducing consumption on the mobility front, an abundance of resources is created for other more strategic sectors of the economy. In this regard, cities must be aimed at cycling and careful planning of the public space, also through the definition of alternative routes, which can bypass the normal transport network, and take advantage of alternative, naturalistic, and safe routes.

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In urban contexts and on individual infrastructures that are particularly significant for the urban development of cycling, when various positive contextual factors lead to a mobilization of different stakeholders and therefore to attention and mobilization of public opinion, when several factors are concentrated on a single objective, the benefits in terms of sustainability and activation of skills multiply. In particular, in the urban context of Pescara, under the fast transport axis that connects Chieti and Pescara, in the path that runs along the river in a highly naturalistic area, seat of disused industrial archaeology and some productive settlements still active, ten years ago it was promoted a cycle greenway. Little frequented and therefore immediately vandalized, the greenway today becomes the focus of numerous ongoing actions, some by the third sector, others by the administration, and still others by the production sector. The convergence underway proves to generate new opportunities for an axis that the Biciplan of the city indicates as part of the backbone network, as it defines strong urban connections, capable of activating new cycling mobility from the most distant suburbs.

2 Integrated Sustainable Mobility

The strategies linked to the objective of sustainable mobility integrated into urban contexts require intermodality, traffic slowdown, development of a safe network as well as strong policies of action and communication with a focus on citizens, stakeholders, and community. People's views and responses to new solutions are important. On the one hand, aligning public opinion with expert and political perspectives can be challenging; on the other hand, ideas and suggestions from citizens, stakeholders, community, and various interest groups also help decision-makers to find better solutions for all. At a European level, however, two very different factors have led to a complete revolution in recent years, which has had an impact on European cities (as emerged in Velo-city, 2022).

1. The COVID, the consequent lockdown and the emptying of public places have shown that when cities are empty and cars are stationary, active mobility by bike multiplies, thanks to the greater safety of the context.
2. The appearance of electric scooters, which has introduced widespread micromobility on all paths (pavements, cycle paths, driveways), has defeated all the strict rules of the highway code and has shown that segregation (clear separation of vehicle flows) can only be operated on certain roads, under certain conditions and in very specific circumstances.

The issue that emerged from these two factors is that if the cars from the roads decrease, the separation of flows (automotive, cycle, pedestrian) no longer has any foundation; consequently, it is not necessary to fill the cities with cycle paths but simply to encourage citizens to give up to the use of the car. If cars drop off the streets, such as during the lockdown, there is no longer any need to design and build cycle paths. In fact, a cycle path is by definition a road dedicated to the flow of cycles (as defined by the law) in which motor vehicles cannot circulate. Somehow in Europe, it has been realized that reasoning in watertight compartments is not a solution to sustainable mobility: for this reason, for example, the national plan for cycle mobility in Belgium was not drawn up by the Ministry of Transport, but is instead being drafted in concert with all ministries in a collaborative and systemic approach, so that it can take on strategic relevance, through concrete and measurable actions.

2.1 More Security Is More Mobility

If the integrated approach is the only possible answer to the necessary increase in mobility, many factors become priorities within the definition of urban strategies:

1. Strategic planning, which identifies future cycle mobility within the urban fabric, identifying primary routes and secondary networks to intercept tractors; in Italy, this function is attributed to the Biciplan urban planning tool (Law 2/2018).
2. The identification of the primary network for safe travel in urban contexts, which can favor the separation of flows or the identification of alternative routes such as greenways to unite the major attractors.
3. The identification of the secondary or widespread urban crossing network, which must favor the sharing of flows in 30 areas with environmental islands, residential areas, school roads, and preferred pedestrian traffic areas, or areas with cycle priority.
4. The communication and education strategy to encourage the use of cycling infrastructures, through awareness-raising actions.
5. The active involvement of stakeholders, starting with the third sector.

The necessary increase in safety as the first reason for the increase in active mobility requires a focus on the main causes of accidents in urban contexts; they can actually be defined as "contributing causes":

1. Maximum heterogeneity in the urban environment in the movements and use of space because the pedestrian, the public transport bus, or the heavy vehicle that is delivering the goods can circulate on the same road.
2. The road infrastructure. The technical standards for road design are designed for an infrastructure that must allow motorized vehicles to move. In fact, all dimensional and performance standards refer to the motorized vehicle, making them more suitable for an extra-urban context.
3. The behaviors of both car drivers and active users: distractions and unsafe behavior of all categories of road users can lead to dangerous situations.

In recent years, Europe has long discussed the most effective approach to increase safety for cycling and safe urban contexts by contrasting two models:

1. The Dutch method based on traffic moderation and space sharing
2. The Danish system based on the separation of mobility flows

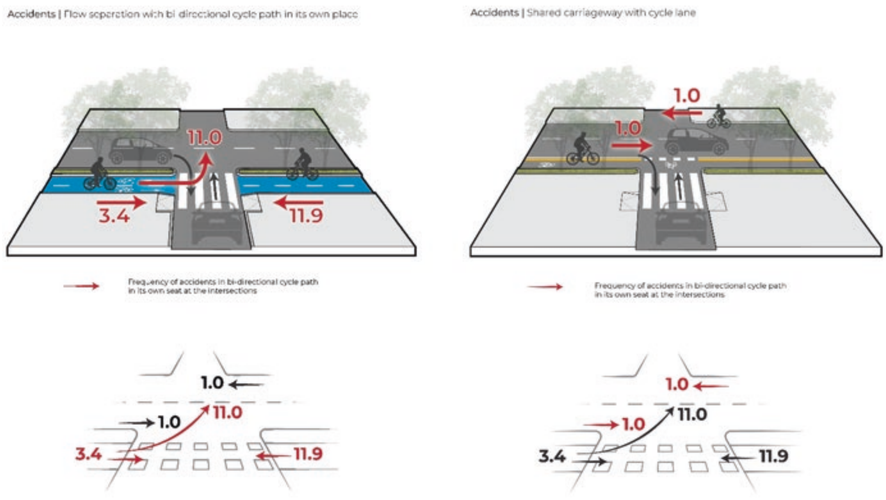

Fig. 1 Elaborated by a study (1993–2003) of the accidents of cycle paths at intersections in urban areas. Direction des travaux publics, des trasports et de l'énergie du canton de Berne – Barbara Egger and Oskar Balsiger, 2003

Today, the answer comes from reality and the two visions must coexist: the systemic approach is the only one capable of giving comprehensive answers to a complex problem such as that of sustainable mobility, which provides, among other things, a large number of stakeholders to give answers. Even the most recent research reveals the greater safety of those who are most visible from the road, and the tendency of cars to slow down when there is interference and therefore greater sharing (Fig. 1).

2.2 *Rediscovery of "Residual" Urban Routes*

In urban contexts, the primary network of cycle journeys represents the backbone of the cycle network of a city and must ensure the connection: with the main traffic attracting poles spread throughout the territory (school and university centers, offices, hospital complexes, etc.), with the main public transport nodes (railway stations, underground stations, interchange parking lots, etc.), and with large environmental systems (parks, green corridors, river courses, etc.).

The strategy for defining the carrier network passes through the identification of the shortest and fastest routes that the cyclist can take, prioritizing the safety of the network which must be:

- Useful and attractive because it connects services and notable points of the city
- Fast and short because it allows you to reach the cyclist's personal target in the shortest possible time

- Continuous because it does not suffer interruptions but can be traveled
- Recognizable because it is reported and identifiable

In this strategy of identifying the main routes, unknown or alternative routes become fundamental, where heavy traffic does not pass, often in correspondence with road axes of greater entity (ring roads or motorway axes) or along river routes often abandoned for years. Given the difficulty of always acting with new cycle paths due to the narrow measures of the streets in the city, a good choice is to also act in the interstices such as potentially crossable green areas or historical paths such as "cavatoni," graveled river axes, public parks, or the recovery of existing infrastructures and structures, such as paths, historic roads, towpaths, disused railway lines, and minor rural roads.

3 The Greenway "Fluvia" of Pescara

In the context of the city of Pescara, an average city of 120,000 inhabitants, but whose conurbation includes other municipalities that will flow into the greater Pescara (Montesilvano and Spoltore) for a total of 200,000 inhabitants, in recent years the approval of the SUMP (2020) and of the subsequent in-depth study on cycling by the BICIPLAN (2022), they defined the programmatic basis for the development of sustainable mobility facilitated by the morphological conformation of the city, with an active comparison with the stakeholders, divided into interest groups, who were informed and participated and shared some programmatic choices. The cycling numbers are not yet encouraging, but an integrated path is being put together for the implementation of sustainable mobility (Fig. 2).

Fig. 2 Pescara BICIPLAN (2022), the primary net, and in green the G1 greenway

Fig. 3 Map and comunication style of ecomuseum

Within the primary network, which develops within the urban fabric, the G1 Greenway is very important. It is a cycle path that needs maintenance and strengthening, improving the condition of no permeability toward the city context and providing it with connections not only with the city of Pescara, but also with the neighboring municipalities to which it stands. The actions cannot only be maintenance, but must be configured as a system of activities that make the path attractive, through a general improvement of safety and a network that also makes it an artery of connection with the peripheries. Furthermore, it is necessary to characterize its green value more, as it crosses green areas and riverside, with stretches of great environmental and landscape quality. In very general terms, a "greenway" is defined as a "pleasant path from an environmental point of view"; in fact, "green" indicates not only what is vegetated but also everything that is appreciable from an environmental point of view and therefore naturalistic, landscape, historical-architectural, and cultural "way," which, in addition to physically indicating the communication routes (roads, railways, rivers, etc.), refers to an idea of movement, communication, and activity. With a view to mobility, "greenways can constitute a system of paths dedicated to non-motorized traffic capable of connecting populations with the resources of the territory (natural, agricultural, landscape, historical, and cultural) and with 'centers of life' of urban settlements, both in cities and in rural areas" [6] (Fig. 3).

3.1 The Greenway as an Urban Distribution Axis

The riverside route that, after the tract of triggering with the city, still fragmented, defines a first urban area, with connections in strategic and peripheral points, and a second more naturalistic section, in which the connections with the urban fabric continue. A multinational company located at the very end of this path, ten years ago financed this riverside cycle path, which passes under the equipped axis in some sections, and in adherence to heavy production systems. This 4540 ml Greenway that runs along the South riverside, after ten years of almost complete inactivity, during which it was vandalized and deprived of lighting, today needs work to connect with its urban entrance and to improve the axis itself, through a system of activities that make the path attractive in order to obtain a general improvement in safety and a network that makes it an artery of connection with the peripheries.

To date, this path is being paid attention to by ongoing projects, organizations, and associations, and a multistakeholder approach is being adopted to restore its urban value. The various projects in progress see the administration concentrate its different souls (youth policies, mobility, cultural heritage, public green spaces, river contracts), in a common goal that concerns the networking of a cycle road axis, through its identification and recognition in a river ecomuseum. The associations involved in nationally funded projects are cleaning, coloring, equipping, and enhancing this path. The company that financed the path ten years ago, today, through significant mobility management for home-work journeys, seeks, together with the others, to increase the critical mass of his journey. All these contemporary projects are in fact returning to the city a place of inestimable value for culture, richness of biodiversity and for cycling urban connections with the most distant suburbs (not only physically, but also on a social level) from the city center.

In this context, the idea of this axis goes beyond that of a simple cycle path, investing more structural aspects that are also linked to the concept of ecomuseum, such as the enhancement and redevelopment of natural resources, the promotion of sustainable development, recovery of degraded landscapes and the harmonious development of cities, and addressing not only cyclists but all non-motorized users. Six main characteristics can be identified that make this axis unique in the urban context:

- Safety, being physically separated from the ordinary road network dedicated exclusively to non-motorized users
- Accessibility, for all types of users with different characteristics and abilities (children, elderly, etc.)
- Integration with the natural environment, which makes it possible to offer respectful access to areas of particular natural value and to carry out an important educational function, allowing knowledge and sustainable use of the territory
- The “gentle circulation,” linked, for example, to the moderate slopes, which allows you to enjoy the routes “slowly,” offering a different point of view on the surrounding landscapes
- Multi-user, as the route is open to all types of users (pedestrians, cyclists, hikers on horseback, etc.)

3.2 The FLUvia Ecomuseum Between Material and Immaterial

The ecomuseum is defined as a nontraditional museum, consisting of an area of territory that preserves, enhances, protects, and makes known its cultural and environmental, naturalistic, and historical-artistic heritage, thanks to the involvement of the community and local institutions. The ecomuseum of the Pescara River will feature six entrances from the city, each of which is marked with vertical signs, a map of the ecomuseum and the point where it is located. This light infrastructure will run along the entire cycle path and also around it and will be able to bring ample benefits for the inhabitants, which go beyond that of having pleasant and safe routes available, such as:

- Contribute to the development of the areas crossed, bringing opportunities for the creation of new entrepreneurial activities
- Favor the spread of outdoor activities along the river, with beneficial effects on the health of citizens
- Promote the development of a new form of tourism, active, responsible, and sustainable
- Promote knowledge of nature and respect for the environment
- Promote the knowledge and enhancement of the intangible cultural, environmental, and landscape heritage, also linked to the historical link with the river

The ecomuseum re-evaluates the tangible and intangible heritage of a territory and reactivates basic knowledge to protect, manage, and transmit it, thus restoring awareness of the landscape as the main common good to take care of [3]. The fruitful contamination between ecomuseum and landscape has generated innovative learning paths and active citizenship in Italy, inspired by the public decision-making process indicated in Article 6 of the European Landscape Convention as identification, characterization, landscape quality objectives, application.

It is the perception that people have of the landscape that legitimizes its recognition and value before the Community. The educational experiences gained with the tools refined by the children who activated a material and immaterial path for the ecomuseum building, are therefore important: landscape explorations, participatory inventories, community maps, connection with the River contract, simple activities open to all, through which we become aware of the importance of the daily landscape for the well-being and for that of the community.

The ecomuseum will feature some “attractions” which will be indicated in the maps and which constitute the main points of the ecomuseum itself:

1. Door of Oaks, the first place on the route where the river becomes the protagonist, equipped with a seat, one of the stations of the life route, street furniture, information totem on the curiosities of Pescara
2. Big Fish on the Risorgimento bridge, an artistic artifact visible from the city, which refers to the river and its value

3. Industrial archaeology pitch—narrative point, life path station, put back in place with murals and coloring of the stone elements present
4. The Decadent Plinth BIG FISH, an artifact close to a plinth of a bridge that has never been used, half hidden in the vegetation, a place for reflection on the landscape, attracted to it
5. At Salice Bianco, narrative point, place for bench and rest, life path
6. Big mallard, near to the entrance to the City of Music with a 1.70 m high wooden mallard on a pitch on the river surrounded by vegetation, just before a linear path with a unique view of the river in terms of landscape and enjoyment, a place of rest and reflection
7. Historical murals and narrative memory, with a text and images on the relationship with the river
8. The clearing and the picnic area, with an area equipped for rest and recreation
9. Histoire d'O on the long north river (a rod with a yellow circle above that frames the Bourbon bath from the north pier, which takes up an idea by the artist Summa)
10. Bird watching and tree species near the entrance to the company located at the end point

The road markings is characterized by the footprint of the mallard along the stretch of the route that goes from the sea it continues along the entire asphalted section of the cycle path and it's coloured in some vertical and horizontal elements

Fig. 4 Some puntual intervention of ecomuseum FLUvìa ecomuseum

with tactical urban planning interventions. A compass with a wind rose is placed on the road surface on the Sea Bridge, to underline the importance of places and symbols and create a shared and attractive space for socializing, rethinking / planning occasions such as stories / legends related to territory, with families, children, the elderly, residents of the area, tourists and school groups. The function is to make the user of the ecomuseum and not only stop at that point and turn their gaze to the surrounding landscape. From the points deemed suitable for carrying out the project, it is possible to clearly recognize the four landscapes of Abruzzo, the sea, the river, the Maiella, and the Gran Sasso (Fig. 4).

4 Conclusion

If mobility, which is the city's operating system and holds together the different applications of the cities, does not work, also commerce, school, or social relations no longer exist. It is therefore evident that mobility cannot be just road traffic management, but requires an integrated and systemic approach [5] where the need for intramodality, traffic slowdown, and development of a safe network [4] goes from hand in hand with policies to discourage the use of private cars, linking themselves to the management of parking lots and improving the use and quality of public space. Integrated policies able to respond to the various stakeholders are fundamental, through particular attention to those green and blue infrastructural axes that for years have been identified as an inaccessible back of the city. The multi-stake holder approach, which involves the Region, the Municipality with all its sectors, trade associations, interest groups, companies present, cultural associations and civil society, only by simultaneously activating a common goal of activating the "forgotten" path of the Greenway, they are able to multiply the benefits. The networking of the daily mobility of the cycle axis in the urban system passes through its identification and collective recognition in the FLUVIA river Ecomuseum, which becomes a privileged public place of beauty and continuity with the city. The strategic objective of the multifunctional enhancement of the urban axis is achieved through a collective mobilization generating value, which no single action, no matter how well remunerated, could do. Holistic strategies on one infrastructure as important for the future slow mobility of the city, could effectively returning to Pescara a new safe connection of active mobility, useful for the future mobility asset of the city. The "transmission" as well as the Anglo-Saxon term "heritage," expresses the idea of knowledge "in motion," active and multidirectional, functional to the comparison and passage of knowledge. The dialogue on the landscape, constantly nurtured among the members of the community, and in the first place among the young people, prefigures a new "school," open, "without walls," where all the skills and abilities contribute to continuous training based on "domestic economy" of the common home, again necessary.

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References

1. European Commission. (2019). The European Green Deal COM/2019/640, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN. Accessed 14 July 2022.
2. European Commission. (2021). New European Bauhaus COM/2021/573, available at: https://europa.eu/new-european-bauhaus/system/files/2021-09/COM%282021%29_573_EN_ACT.pdf. Accessed 14 July 2022.
3. Magnaghi, A.(2020). Il principio territoriale, Bollati Boringhieri
4. Mastrolonardo, L. (2021, December). Sustainable mobility and beauty of public space. *VITRUVIO - International Journal of Architectural Technology and Sustainability,* [S.l.], *6*(2), 42–55. https://doi.org/10.4995/vitruvio-ijats.2021
5. Mussinelli, E. (2018). Il progetto ambientale dello spazio pubblico, Eco-WebTown. *Journal of Sustainable Design, 2*(18).
6. Salici, A. (2013). Greenways as a sustainable urban planning strategy. *Advances in Landscape Architecture, 10*, cap. 24.

Urban Green Infrastructure for Planning Sustainable Communities: A Methodological Approach to Assess the Effects on the Territories

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1 Introduction

In the debate on defining the concepts of urban quality and sustainable and resilient urban development [1], urban green infrastructure plays a role of strategic importance [2]. The implementation of green infrastructure in urban contexts is a key issue in national [3] and EU [4] policies for the pursuit of decarbonization and, more generally, quality-of-life improvement goals. Many studies [5] in recent years have investigated the potential of green infrastructure in sustainable urban planning. Programmatic approaches and directions have defined strategies and technologies that, at different scales, can help address the global challenge of climate change: mitigating the impacts of anthropogenic pressure and improving urban resilience [6, 7]. Ongoing discussion and observation [8] of advanced best practices in the international arena, including the example of Barcelona [9] and Paris [10], have shown their multiple environmental and socioeconomic benefit: a new quality of living in urban fabrics, new and more responsible mobility habits, new land and local resource uses, new social ties and processes, new landscape values and new economies.

The paper reports on part of the research work developed as part of a research project of the DAStU of Polytechinc of Milan that proposes to apply the logic of role-playing [11, 12] as a playful, open, and collaborative tool that engages the community in urban transformation planning processes. The paper reports an in-depth study related to the implementation of an urban green infrastructure in the municipality of Rescaldina in the Milan metropolitan area. The methodological is based on a participatory approach that, through experiencing processes and with the help of

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quantitative assessment methods and tools, aims to make verifiable the results that certain transformations may determine on the local ecological footprint of a community. The construction of verifiable scenarios constitutes a tool for understanding the environmental and economic effects of certain project choices. It also serves as a tool for comparison to assess the degree of social acceptability by the community of the transformations to be made and debate to validate choices to co-construct shared processes for the transition to more sustainable patterns of living in a community.

2 From Gray Infrastructure to Urban Green Infrastructure

In the modern era, “gray” infrastructure has been a key determinant of urban expansion and the territories’ socioeconomic growth. Accessibility to individual mobility became a symbol of progress and the automobile an emblem of the consumerist development model. Today we know that this development has become unsustainable. Dwelling on the national condition, mobility is associated with the responsibilities for about 25% of total greenhouse gas emissions, 92.6% of which are from road transport: 62% of total emissions are determined by travel by private vehicles powered by fossil fuels. According to ANFIA [13] and ISOFORT [14] data on average each individual traveled 28.2 km daily, of which 70% were for trips of less than 50 km with a mobility demand of 75% for trips of less than 10 km. 71% of the km traveled was by private mobility (cars and motorcycles), 23.5% by public mobility, and 5.2% by walking or biking. At the urban level, trips made on foot accounted for 31.3% and those made by bicycle for 5.6%, public transport trips accounted for only 9.3%, while those made by car and motorcycle accounted for 53.8%. At the extra-urban level, trips made by bicycle accounted for 2.4%, while those made by private vehicles accounted for 86% and those made by public transport for only 11.7%. Some surveys [14, 15] have shown that a good percentage of individuals declare a willingness to change travel habits in favor of public transportation, micro-mobility services (bike and scooter sharing), or sharing mobility. Although the current figure was influenced by the COVID-19 emergency, in general, the propensity to use alternative mobility is manifested according to certain factors that condition the quality of the servic, accessibility, safety, comfort, cost, travel time, punctuality of public transportation, effectiveness connection with interchange nodes, effectiveness connection with basic services. The same research points out that in recent years, COVID-19 restrictions have increased urban travel within 15 minutes with a rediscovery of proximity spaces (up to 2 km). This dimension of livability, free from congestion from traffic, smog, noise, and visual disturbances, although reabsorbed by the reactivation of vehicular flows in the post-restriction, has led to an increase in ecological awareness and orientation toward new mobility habits of citizens, which could be a determining factor in achieving transition goals toward sustainable mobility.

Against this background, the conversion of gray infrastructure to urban green infrastructure is a strategy that is most urgently needed to be developed in urban transformations that favor alternative mobility to the private car, with results on environmental and ecosystem quality and reduction of the impacts on the urban system (pollution, noise, congestion, occupation of public land by vehicles).

The concept of urban green infrastructure refers to a design approach that "*aims to develop networks of green and blue spaces in urban areas, designed and managed to deliver a wide range of ecosystem services and other benefits at all spatial scales*" [16]. The strategy is based on four principles:

- *Green-gray integration: aims at physical and functional synergies between urban green space and other kinds of infrastructure, such as transport system and utilities.*
- *Connectivity*: builds networks between different spatial scales (neighborhood, city, territory) and improve connections between ecosystem components to support and protect natural and social processes.
- *Multifunctionality:* combines different functions to improve the ability of urban space to provide multiple benefits: environmental, social, and economic.
- *Social Inclusion*: implements collaborative and socially inclusive processes with open planning that gathers the knowledge and needs of different stakeholders.

The concept of urban green infrastructure arose in response to the EU policy push toward the implementation of green infrastructure defined by the European Commission as "a strategically planned network of natural and seminatural areas with other environmental features designed and managed to deliver a wide range of ecosystem services [...]" [17] that is "*[…]* the benefits people obtain from ecosystems." In other words "*ecosystem goods and services*" [18], which include: provisioning services that provide humankind with products and resources from ecosystems (food, water, raw materials); regulating services that include the control of pollutant phenomena, flows (water, matter, and energy), and physical, chemical, and biological conditions (including local microclimate and self-purification); cultural services, that is spiritual benefits in the recreational enjoyment and identity of places.

By applying these principles in the regeneration processes of public spaces and urban infrastructure, it is possible to advocate a reorganization of urban space that, by taking space away from traditional mobility (lanes, parking spaces), encourages the integration of green mitigation spaces (green spaces for bioretention and infiltration, collection for rainwater or domestic water reuse) with other urban functions (spaces for sociability and food and energy production). These functions can be integrated with spaces dedicated to alternative mobility: bicycle and pedestrian paths, waiting spaces, bicycle workshops, velostations, and spaces for parking and recharging electric or shared vehicles. In this direction, it is desirable to facilitate access to the use of "soft" means by facilitating for the inhabitant the use of alternative means (bicycle, public transport, shared means, electric means) in an integrated way, so that he or she can complete the daily route in the short or medium-long journey easily and in a safe, comfortable, and convenient way.

In this direction (although still partial), the research activities set forth in this contribution represent an attempt to provide decision makers and communities with tools for knowledge and verification of the effectiveness of process and design solutions in the context of territorial regeneration initiatives through urban green infrastructure planning.

3 Methodology and Results of the Case Study

The method proposed in TRAceS research is based on a game-based learning approach in which collaborative approaches and digital technologies support the performance response of design actions in building carbon neutral housing scenarios [19]. The design process is structured by sequential and iterative steps that augment project data and information until a final outcome is reached that is shared among the various stakeholders. The resulting tool is intended to configure a framework for the integration of technological and functional solutions in urban settings that aims to highlight the transformations potential to be made in support of a neutral transition of territories. It also aims to build a framework for gaining knowledge related to project variables, contextualizing solutions applicable to the specific context. The basic framework relates variables that influence the design process concerning:

- Characteristics of the urban fabric (morphology, infrastructure, services and their distribution, open space categories and uses)
- Modes of use, lifestyles of inhabitants, propensity to change daily habits of movement, and access to everyday goods and services.
- Scientifically recognized functional solutions and technologies.
- Design performance in context, in terms of environmental, economic, and social effects.

Each possible action is described in fact sheets that represent the playing cards in which the performance of the individual variable is made explicit by describing the effects of behavior changes that the community is expected to accept and structural changes to the built environment that the project is expected to accommodate. Each action has an effect in terms of changing the amount of CO_2 emitted for the production of a good or service by coupling it with the amount of land committed to the production of the primary goods [20], the economic cost to accomplish the specific activity, and the time commitment. During the game, players are asked to understand the impacts their daily habits have on the local ecological footprint and experiment with actions that result in changes in their behaviors toward more responsible habits. This phase (Player) is set up as a tool to learn about the conditions that hinder virtuous behavior on the part of users. The interpretation of the data in the next phase (Design) allows understanding the effectiveness of design actions that in context can achieve concrete results and build shared scenarios of urban sustainability.

Table 1 Average annual impacts for the mobility category in the municipality of Rescaldina estimate based on national data

Distribution referring to the km traveled within the municipal perimeter of Rescaldina	% km	Until km traveled in a year	Impact in mq	Impact in t CO_2 eq	Costs €
Private mobility	53.80%	77.357.212	92.828.654,78	40583.24	23,207,164€
Public mobility	9.20%	13.372.158	17.116.361,63	7161.75	4,011,647 €
Cycling	5.60%	8.052.052	–	–	161,041 €
On foot	31.30%	45.055.218	–	–	–
TOTAL IMPACT ab	***100.00%***	***10,330***	***9730***	***3,43***	***1967 €***

3.1 Case Study Description

The municipal territory of Rescaldina covers an area of 8.20 square kilometers and is home to a population of 13,920 inhabitants. The territory is more than 60% urbanized, with land use predominantly residential (28%) and tertiary (16%). The mobility system (roadways, car parking spaces, and sidewalks) occupies about 10% of the total area, while only 1.6% is destined for green spaces (street green and uncultivated areas).

Applying the simplifying procedure that characterizes the method developed in the research, it is estimated that to support the lifestyles of the settled community in the municipality of Rescaldina, an area of about 40 times the existing area is needed. The impacts are grouped according to 6 categories representing the main expenditures that the population incurs for access to goods and services of daily use (mobility, food, housing, clothing, recreation and communication, education, and other basic services). Dwelling on the mobility category (Table 1), it is attributed a per capita land consumption per inhabitants of 9730 m^2 and emissions of 3.43 tCO_2eq. The figure refers to national statistics (ISTAT, ISFROT, ANFA) and overall represents the share determined by trips made by private means (53.8%) and of trips made by public means (9.3%). Impacts are derived from the average number of kilometers traveled annually in the municipality by applying conversion factors to transform kilometers into m^2 of land consumed and CO_2 emitted. These factors take into account the number of trips per motorized inhabitant broken down with respect to the total number of households residing in the municipality of Rescaldina, vehicle type by fuel type, average mobility expenditures, average consumption by vehicle type, and average impacts on km traveled.

3.2 Construction of the Intervention Scenario and Impact Estimates of Project Alternatives

Based on these observations, the study proposes some strategies cast in the context of municipality of Rescaldina, by which impact reductions. The assessments are estimated according to simplified procedures that tend to assess the environmental impacts of project alternatives that may affect the behavior of inhabitants. The proposed strategies are contained in a transformation scenario that envisages the creation of an urban green infrastructure connecting places of public interest and the main interchanges with other forms of mobility (railway station) in the municipal area of Rescaldina (Fig. 1).

The location of the route is the result of an in-depth study of the characteristics of the urban fabric. The strategy is particularly aimed at improving the conditions of the use of paths dedicated to sustainable mobility to encourage their use by the community by accommodating their daily needs. The bicycle and pedestrian path would

Fig. 1 Graphic illustration of the method

be made accessible within a radius of 300 m. Parking spaces dedicated to the parking of "traditional" vehicles converted with spaces intended for velostations, cycle workshops, electric vehicle charging stations, parking for shared-use and electric vehicles, and other proximity services.

For each solution, each corresponding to an action in the "project actions" deck of cards, the effects in the impact changes were preliminarily calculated with the aim of enabling the construction of alternative intervention scenarios. An initial experimental test was conducted through simulations carried out by the research team. Specifically, the results of project alternatives among those proposed were investigated in depth to understand their degree of effectiveness in contention. In the hypothesized scenario, the construction of the bicycle and pedestrian path alone, if enjoyed by the entire population, assuming the use of the trips usually made by private vehicles by the motorized population, would result about 50% reduction in impacts by returning an area of about 15,000 m^2 to the territory. Conversion of some of the parking areas dedicated to vehicle parking would result in a reduction in impact of about an additional 40%. This related to the reduction in the number private fossil-fueled vehicles that would circulate in the municipal area and the creation of urban functions (recreational spaces, community gardens and vegetable gardens, cycle workshops, velostations) and mitigation functions (green spaces for bio-retention and infiltration, rainwater harvesting or domestic water reuse).

The results show different levels of uncertainty that express the need for robust experimentation with a wider audience to verify the calculation procedures and validate the impacts described in the individual actions.

4 Conclusion

The research focuses on experiments to simulate transformation alternatives of the built environment aimed at understanding the propensity of the territory and its inhabitants to change resilience. The methodological approach prompts a consideration of changes in human behaviors that modifications to the built environment can bring about, for example: the propensity of the community to use bicycles; the propensity of the population to forego the use of private cars in favor of public mobility; the propensity of the population to use shared mobility; understanding the extent to which urban infrastructure is capable of facilitating the attainment of goods and services of daily use through sustainable mobility; understanding the extent to which certain transformations are feasible on a given context; understanding the feasibility with respect to the characteristics of the urban system; and understanding the feasibility with respect to available economic resources. These processes presuppose a collective commitment among the various actors involved in spatial planning. They also require an increase in knowledge and responsibility on the part of the entire community to achieve urban quality and sustainable urban development goals. Developments in the research will be aimed at strengthening the methodological approach by opening up to interdisciplinary collaborations aimed at improving the degree of effectiveness and practicability in the method and further design solutions that will be the subject of the in-depth investigations of the next stages of the research, preliminary to the testing of the game in the municipality of Rescaldina.

References

1. Ahern, J. (2013). Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology, 28*, 1203–1212. https://doi.org/10.1007/s10980-012-9799-z
2. Pauleit, S., Ambrose-Oji, B., Andersson, E., Anton, B., Buijs, A., Haase, D., Elands, B., Hansen, R., Kowarik, I., Kronenberg, J., Mattijssen, T., Olafsson, A. S., Rall, E., P.N. van der Jagt, A., & Konijnendijk van den Bosch, C. (2019). Advancing urban green infrastructure in Europe: Outcomes and reflections from the GREEN SURGE project. *Urban Forestry & Urban Greening, 40*, 4–16., ISSN 1618-8667. https://doi.org/10.1016/j.ufug.2018.10.006
3. Governo italiano. (2021). *Piano Nazionale di Ripresa e Resilienza*. Available at: https://italiadomani.gov.it/it/home.html. Accessed June 2022.
4. European Commission. (2019). *The European green deal*. Available at: https://eurlex.europa.eu/legalcontent/EN/TXT/?qid=1588580774040&uri=CELEX:52019. Accessed June 2022.
5. Mell, I. C. (2017). Green infrastructure: Reflections on past, present and future praxis. *Landscape Research, 42*(2), 135–145. https://doi.org/10.1080/01426397.2016.1250875
6. Anderson, E. (2018). Functional landscapes in cities: A systems approach. *Landscape and Ecological Engineering, 14*, 193. https://doi.org/10.1007/s11355-017-0346-6
7. UNEP. (2014). *Green infrastructure guide for water management. Ecosystem-based management approaches for water-related infrastructure projects*.
8. Coppola, E., Zaffi, L., & D'Ostuni, M. (2022). From superillas to tactical greenery. Experiments and transcalar strategies of vegetal regeneration of urban space. *AGATHÓN – International Journal of Architecture, Art and Design, 11*, 62–73., ISSN print: 2464-9309 – ISSN online: 2532-683X. https://doi.org/10.19229/2464-9309/1152022
9. Rueda-Palenzula, S. (2019). El Urbanismo ecosistémico. *Ciudad y Territorio, 51*(202), 723–752. [Online] Available at: recyt.fecyt.es/index.php/CyTET/article/view/77733/48005. Accessed July 2022.
10. Moreno, C. (2020). Projet Portes de Paris – Ville du Quart d'Heure Territoire de la Demi-Heure – Transitions Urbaines et Territoriales, Livre Blanc. [Online] Available at: chaire-eti.org/wp-content/uploads/2019/12/Livre-Blanc-2019.pdf. Accessed July 2022.
11. Rogora, (2020*),* New proposals for sustainable design: The imitation game as an experience of shared co-design*, in* Sustainability in energy and buildings 2020*,* John Littlewood Robert J. Howlett Lakhmi C. Jain *Editors,* Springer Nature Singapore - ISBN 978-981-15-8782-5 – (pag. 527–537*).*
12. Romano M.*,* Rogora A.*, (*2022*),* Serious game: New tools for exploring and designing urban sustainability,. in press.
13. ANFIA. (2021). *Dossier Trasporto passeggeri e mobilità. Focus sul trasporto collettivo su gomma*.
14. ISFORT. (2021). *18° Rapporto sulla mobilità degli italiani. Governare le transizioni per una ripresa sostenibile*. Available at: https://www.isfort.it/wp-content/uploads/2021/11/211130_RapportoMobilita2021.pdf. Accessed June 2022.
15. Moovit. (2020). *Rapporto mondiale sulla mobilità pubblica*. Available at: https://moovitapp.com/insights/it/Analisi_Moovit_sull_indice_per_la_mobilit%C3%A0_pubblica-countries. Accessed June 2022.

16. Hansen, R., Rall, E., Chapman, E., Rolf, W., & Pauleit, S. (Eds.). (2017). *Urban green infrastructure planning: A guide for practitioners*. GREEN SURGE. Retrieved from http://greensurge.eu/working-packages/wp5/
17. European Commission. (2013). *Directorate-general for environment, building a green infrastructure for Europe*. Publications Office. https://data.europa.eu/doi/10.2779/54125
18. MEA – Millenium Ecosystem Assesment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press.
19. Romano, M., Clementi, M., & Rogora, A. (2022). TRAceS: processi sperimentali per simulare scenari abitativi "carbon neutral". *TECHNè - Journal of Technology for Architecture and Environment, 24*. in press.
20. Berners-Lee, M. (2020). *How bad are bananas? The carbon footprint of everything*. Profile Books Ltd.

Building a Healthier Living Environment for People and the Planet: A Case Study Review

Livia Calcagni and Alberto Calenzo

1 Introduction

Worldwide forecasts estimate that 6 out of 10 people will live in cities by 2030 [1], a figure that will reach 7 out of 10 by 2050 [2]. This progressive increase has led the scientific community to explore and assess the salutogenic effects linked to urban environment and buildings [3]. The paradigmatic shift from health as the simple absence of disease to a state of physical, mental, and social well-being has broadened the disciplinary domain of health to the field of architecture and urban environment. In particular, indoor building-related factors that influence health, well-being, and productivity [4] take on significant importance if we consider that we spend 90% of our time indoors [5–7].

These factors embrace environmental hazards (radiological, chemical, biological, physical) [8], building design, (ventilation, pressurization, filtration, lighting, acoustics) [9, 10], social factors (location, safety) [11], behavioral factors (curriculum, work activities, wellness programs) [12], adjacent land use (chemical releases, walkability, noise sources, green spaces) [13], architectural design (physical activity promotion, eating spaces, material selection, biophilic design, and access to natural lighting) [14, 15], and operations and maintenance (preventative maintenance upkeep, cleaning, integrated pest management) [16, 17]. Other potential health threats due to indoor exposure, mentioned in literature, include radon and lung cancer [18], phthalates and asthma [19], second-hand smoke and increased risk of premature death [20]. All these socioeconomic, behavioral, environmental, genetic, and health factors which have significant effects on health can be described as the

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"social determinants of health," as identified by Dahlgren and Whitehead [21] and further developed in Barton and Grant Settlement health map. The determinants of health are the ones that affect the prevalence of NCDs (noncommunicable diseases), which currently account for 86% of deaths and 77% of illnesses in European regions [22].

The adoption of a salutogenic approach, which envisages preventive strategies and measures that reduce the incidence of disease in the first place, requires addressing urban welfare and health in a transdisciplinary way, as major international institutions are doing. For instance, the Agenda 2030 Sustainable Development Goals represent a unique opportunity to promote urban health through an integrated approach to public policies across different sectors. Although health has a central and own position in the agenda (SDG 3), it is closely linked to over a dozen targets in other goals related to urban health, and its achievement will depend on progress in other SDGs that directly impact health [23]: SDG 1 (no poverty), SDG 2 (zero hunger), 5 (gender equality), 6 (clean water and sanitation), 7 (affordable and clean energy), 9 (industry, innovation and infrastructure), 11 (sustainable cities), 12 (responsible consumption and production), 13 (climate action), and 15 (life on land).

The broad alignment of environmental and health agendas underlines the close relationship that occurs between healthy and green environment/building. By definition, green buildings focus on minimizing environmental impacts through reductions in energy usage, water usage, waste production, and CO_2 emissions. Less widely recognized is the fact that green buildings also address human health through the design of healthy indoor and outdoor environments. This superimposition of green and healthy concepts requires the adoption of a human-centric approach, where the planet's health is conceived as part of human's health and well-being.

Although considerable literature has been produced regarding these factors, there is no overall integrated framework which organizes all scientific and institutional contributions. This paper attempts to outline and organize what has been identified so far and what standards have been developed. In order to do so, 4 organizations and initiatives—which play a key role in linking building users' health and well-being to building performance and characters—have been analyzed, systematized according to 17 broad parameters, more precisely 8 measurable ones (temperature, sound, lighting, air, water, occupancy, accessibility, pollutants/dusts/pests) and 9 nonmeasurable ones (safety, food, lifestyle, setting, behavioral engagement, nature, ambience, resilience/climate action and social capital).

This has allowed us to compare the main indicators tracked by each initiative and to outline a comprehensive framework of the major indicators that can be found in literature. Following are the 4 literature contributions selected:

- *9 Foundations of Healthy buildings,* Harvard T. H. Chan School of Public Health programme led by Joseph Allen (2017).
- *WHO Housing and health guidelines*, drawn up by the World Health Organization (2018).
- *Better Places for People Programme*, by the World GBC and Green Building Council (2020).
- *Level(s) Framework*, developed by the European Commission (2021).

WELL Building Standards, developed by the International Well Building Institute (2016), represent another significant contribution which has been taken into consideration as it is the first and only standard of its kind that focuses solely on the health and well-being of building occupants. More precisely, WELL identifies 100 performance metrics, design strategies, and policies that can be implemented by the owners, designers, engineers, contractors, users, and operators of a building. Therefore, each parameter within the framework has been studied also under the lens of the WELL Building Standard rating system and associated to its relevant features.

Grounded in the UN Sustainable Development Goals, the developed framework intends to organize the most significant international contributions with the aim of detecting all the different building-related health parameters, encompassing the widest range of areas (Fig. 1a, b) represents a cross-sectoral analysis across the entire building and construction characters and lifestyle, redefining the scope of health for all people and communities, through the identification of broad topics, each articulated in specific parameters.

2 Correlations Between Health and Building-Related Factors

NCDs, noncommunicable diseases, currently account for 86% of deaths and 77% of diseases in European regions [22]. These are all those diseases linked to socioeconomic, cultural, and environmental determinants. The awareness that pollution, sedentariness, poor nutrition, unhealthy living conditions on the one hand, and social exclusion, isolation and dis-empowerment on the other, contribute to the development of mental illnesses and new chronic "epidemics," such as obesity, diabetes, allergies, and respiratory diseases, has drawn attention to the role that urban planning and architectural design can and should play in delivering health improvements by reshaping the urban fabric and confined environments. Comprehensive and interdisciplinary approaches are necessary to meaningfully address the complex issues of human health and well-being. A narrow focus on selected aspects of health is inadequate to the task, since it is often the interactions between multiple environmental factors that have a significant impact on day-to-day health and productivity. A growing body of evidence highlights that improving inhabitants' living conditions not only affects physical and mental health but also maximizes the performance of their indoor activities: sleep, study, work, relaxation, and socialization. Therefore, improving the housing conditions also contributes to productivity and socioeconomic empowerment [24].

As evidenced by the WELL Building Standard, each factor can be ascribed to the human body systems that are intended to benefit from its implementation. Each building-related factor with health effects affects different systems of the human body, involving 10 of the main systems:

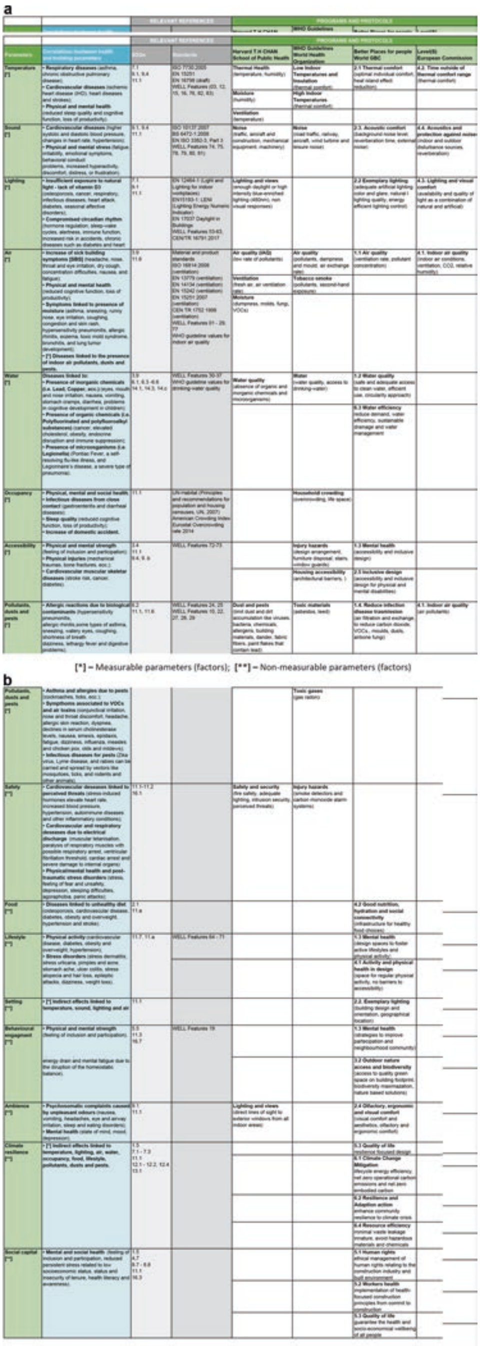

Fig. 1 (**a**) Literature review comparative matrix on building-related health measurable factors. [*] – Measurable parameters (factors); [**] – Nonmeasurable parameters (factors). (**b**) Literature review comparative matrix on building-related health nonmeasurable factors

- *Cardiovascular system* (temperature, safety, accessibility, sound, lighting, food, lifestyle)
- *Digestive system* (temperature, lighting, air, water, occupancy, food, lifestyle, pollutants-dust-pests)
- *Endocrine system* (lighting, food, pollutants-dust-pests, lifestyle, nature)
- *Immune system* (temperature, sound, lighting, air, water, occupancy, safety, setting, food, lifestyle, pollutants-dust-pests, accessibility, climate resilience).
- *Integumentary system* (occupancy, accessibility, air, water, pollutants-dust-pests)
- *Muscular system* (occupancy, accessibility)
- *Nervous system* (temperature, sound, lighting, air, water, occupancy, safety, food, lifestyle, nature, ambience)
- *Reproductive system* (lighting, air, pollutants-dust-pests).
- *Respiratory system* (temperature, air, lifestyle, pollutants-dust-pests, am).
- *Skeletal system* (temperature, lighting, air, safety, accessibility, ambience).
- *Urinary system* (water, food, pollutants-dust-pests).

3 Research Strategy and Methodology

Given the objective to provide an overall knowledge framework and identify invariants and relevant strategies to be adopted in any context to ensure the user's well-being, an analytical framework—which identifies the correlation between strategies and building-related factors—has been created based upon an investigation of case studies that are considered best practices in the field. The selected case studies are considered to be successful projects given their direct effect on occupants' well-being and the positive externalities generated toward their surroundings. The case studies (Figs. 2, 3, 4, 5, 6, 7, 8 and 9) are identified in different geographical and climate contexts and are selected by virtue of their degree of pertinence to a performance-oriented and salutogenic design approach. In particular, eight useful examples of healthy buildings are selected among different functional categories (i.e., residential, public services, offices/schools, and healthcare facilities). In order to address the common reliance on indirect, lagging, and subjective measures of health, the case studies are selected and analyzed according to direct, objective health performance indicators, deduced from a critical synthesis of the most significant contributions found in up-to-date literature. Although the research focuses on a limited number of case studies, the paper reveals some strategies that can be applied to several building in different locations and could be used to support decision makers (DMs) from different countries.

The final purpose of the research is to perform a generalizing and not a particularizing analysis, with the intent to expand and generalize theories (analytic generalization) instead of enumerate frequencies (statistical generalization [25, 26]. According to the case study method, each case study can represent a complete study,

Fig. 2 Case study 1 (CS 1)—Squid Toilet

Fig. 3 Case study 2 (CS 2)—Green (Rose) Toilet

Fig. 4 Case study 3 (CS 3)—Lunder Building

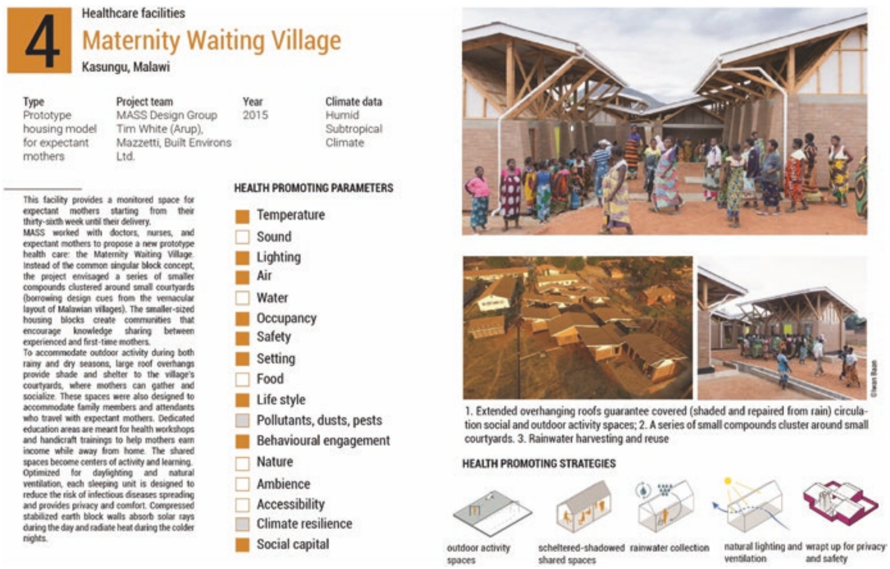

Fig. 5 Case study 4 (CS 4)—Maternity Waiting Village

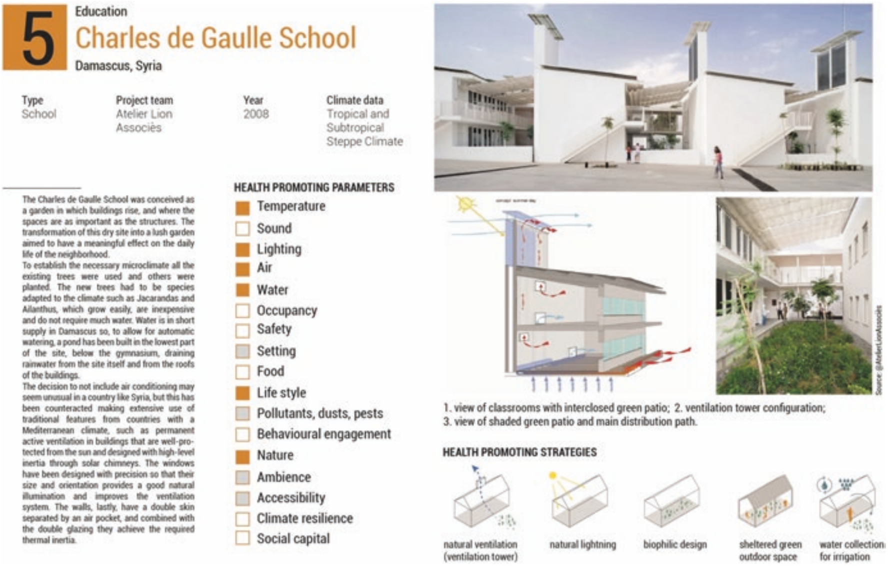

Fig. 6 Case study 5 (CS 5)—Charles de Gaulle School

Fig. 7 Case study 6 (CS 6)—Manitoba Hydro Place

Fig. 8 Case study 7 (CS 7)—Haskell Health House

Fig. 9 Case study 8 (CS 8)—Mariposa District

from which one can detect evidence provided by its conclusions, therefore supporting the overall theory definition.

As these projects show, while the health and climate impacts from building-related factors are not only significant but also complex, the executive strategies are straightforward and can address different issues (factors) simultaneously, proving on a whole the feasibility of implementing simple strategies to obtain great benefits. For instance, simple expedients, such as a detached roof or a porous brick pattern, allow air flows achieving significant ventilation improvements. In turn, natural cross-ventilation contributes to the reduction of moisture and heating as well as to improving air quality. Moreover, requirements associated with one single factor can be satisfied by several strategies, depending also on the specific site conditions. The following parameters described with their relevant strategies referred to the cases study with abbreviation CS, followed by the specific case study number (CS 1, CS 2, etc.).

- *Temperature*: Temperature can be addressed through the implementation of active strategies (radiant floors as in CS 6–7) and passive strategies (ventilation strategies as in CS 5, 6, 7; inner courtyards as in CS 4 and 5, intrusion of nature indoors as atrium garden in CS 3 and 7; optimization of the building envelope performance as in CS 3, 5, 6; shading systems as in CS 4, 6). In CS 1 and 2 temperature control is indirectly ensured by measures related to ventilation.
- *Sound*: Acoustic comfort is guaranteed through appropriately designed internal partition walls in between different environmental units (CS 3) as well as through natural sound barriers placed along the edge of the plot to create a filter with the street (CS 7).
- *Lighting*: A high indoor lighting level and quality can be guaranteed either using a specific construction material such as opaque glass vertical partitions (CS 1), either through a correct sizing and placement of openings according to orientation (CS 3, 5, 6), either by a specific building envelope morphology like the brick pattern of CS 2.
- *Air*: Air quality and good ventilation are satisfied through ventilation towers/solar chimneys in CS 5, 6, 7, by maximizing natural ventilation through inner courtyard configurations (CS 4, 5) and through sizing and placing of openings (CS 6, 7). In addition, a detached roof as in CS 1 e 2 can ensure air flows and exchange while guaranteeing privacy. For what concerns air quality nature intrusion in indoor environments can contribute significantly to CO_2 sequestration and to the reduction of dust and pests (as in CS 3,5, 6).
- *Water*: Water-related factors, mainly related to water efficiency, and management, are generally addressed through rainwater harvesting, purification, and reuse systems, developed with different techniques in CS 2, 4, and 5. For instance, while in CS 2 and 4, rainwater is collected through simple devices and reused for cleaning and washing purposes, in CS 5, it is the entire site that contributes to the collection. More precisely, a pond has been built in the lowest part of the site, draining rainwater from the site itself and from the roofs of the buildings.

- *Occupancy*: CS 3 provides evidence of how a proxemics-oriented design, which pays particular attention to supplying the entire range of interpersonal spatial zones (intimate, personal, social, public), can affect the occupants' overall well-being, especially within a sanitary facility. CS 8 follows strict rules in the internal layout concerning the number of users per square meter in order to avoid overcrowding conditions.
- *Safety*: Safety in the sense of perceived and actual threats can be addressed through the use of semitransparent exterior walls in the case of CS1. This allows users to check the cleanliness and whether anyone is using the toilet from the outside. Good artificial lighting conditions also contribute to strengthening the feeling of safety in public environments at night (CS 1).
- *Food*: Food production as in healthy nutrition and social connectivity is pursued through onsite cultivation of edible plants as a way to recycle waste products (excrements turned into organic compost) and produce fresh products fostering awareness on the need for a healthy diet in CS 2; as an infrastructure for healthy food choices, self production, and social engagement (urban gardens) in CS 8; and exclusively as a means for a healthy diet in CS 7.
- *Lifestyle*: Shaded and sheltered outdoor spaces (as in CS 4 and 7) foster outdoor activity and social cohesion affecting positively both active lifestyle and social well-being as in sense of community and involvement. Housing units equipped with external appurtenant spaces encourage occupants to spend more time outdoors (CS 7). If internal horizontal and vertical distribution is accessible, visible, attractive, and well-lit (CS 3, 6), users are more likely to be active inside the building integrating physical activity into their everyday routine. Last but not least is the potential of a building to create economical opportunities such as job creation as in CS 2 and 4.
- *Pollutants, dust, pests*: The use of vegetation can affect air quality and therefore contribute to the removal of pollutants, dusts, and pests (as in CS 3, 5, 6, 7). The choice of building components and furniture is crucial as well, as in CS 3, where nontoxic materials are always preferred. Water availability achieved through the additional supply coming from rainwater collection (CS 2, 4 5) ensures a daily cleaning and washing routine and with this a clean environment.
- *Behavioral engagement*: This factor is conceived as the opportunity for the user to interact, in different ways, with the building. In CS 6, occupants can control their individual environment according to their own personal preference using operable windows and lighting and shading devices. It demonstrates how comfort behaviors influence energy consumption. The control the occupants can exert over the environment also influences their perception of comfort. The design and development of CS 8 followed a people-oriented approach by fostering a participatory process that led to the definition of site-specific goals related to the needs of the local citizens. This initiative strongly addressed community engagement, social cohesion, and well-being.
- *Nature*: Biophilic design as in occupant access to nature within indoor environment is achieved through the provision of an atrium garden in CS 3 and 6, through direct access to outdoor quality green spaces (CS 7,8).

- *Ambience*: Considering ambience as a factor that embraces visual comfort (lighting and quality of views), olfactory comfort, and ergonomic issues, several different strategies are adopted. For instance CS 3,4,6,7, although in different ways, guarantee direct lines of sight to exterior windows from more indoor areas as possible. CS 1 and 2, environments which are more likely to smell because of their function, pay special attention to constant air exchange and ventilation.
- *Accessibility*: Inclusive design and accessibility design standards are followed, accordingly with relevant national regulations, in all the projects. In CS 1 special attention is paid also to gender equality as all users have access to the same facilities. In particular, vulnerable environments (such as CS 3) rooms are designed to have soft lighting, specific colors depending on the function, large garden-themed graphics, and both open and intimate spaces to create a sense of calm and mental stability.
- *Climate resilience*: Resource efficiency is achieved through minimal waste leakage in nature, improvements in lifecycle energy efficiency through a combination of active and passive strategies in CS 1, 2, 4, 5, 7, 8.
- *Social value*: The creation of positive social impact implies minimizing construction workers exposure to hazardous materials and toxic substances, creating social and economic opportunities with an indirect impact on health and well-being, such as employment opportunities (CS 1,2,4,6,8) or access to education (CS 2).

4 Conclusion

Literature review reveals how one of the major limitation of the field of study is the reliance on indirect, lagging, and subjective measures of health. Moreover, not all health indicators (factors) are actually measurable. Only a few parameters of indoor environmental quality performance can be measured according to true objective measures of occupant health and standardized health metrics, such as temperature and humidity, air quality and ventilation, sound, lighting, pollutants, dust, and pests concentration. Other parameters, including occupancy, accessibility, and safety, are not strictly measurable but still subject to standardization at the discretion of local regulations. More precisely, some of the parameters which cannot be truly defined as measurable (i.e., lifestyle, safety, food, and nature) are measurable in their effects, for instance, sleep quality, anxiety levels, depression, healthy diet, and statistical incidence of some sub-parameters, but listing them all is beyond the scope of this paper.

Currently, there is still no certified system that defines all the building-related parameters that affect occupants' lives, comfort, and well-being. The WELL Building Standard partly does, but it skips some of the features identified by means of our crosscutting literature review focused on programs and initiatives on healthy buildings. For instance, parameters like occupancy, safety, nature and climate resilience, which are identified—partly by WHO Guidelines and Harvard's Protocol, and entirely by Better Places for People World GBC—are missing. The systematic comparative matrix (Fig. 1a, b) highlights how the perception of well-being must be considered as a multisensorial experience that includes at least thermal comfort, visual comfort, indoor air quality, ventilation, acoustic comfort, and spatial comfort, which are common to all the analyzed programs. Yet it is absolutely necessary to consider, in addition to these purely technical factors, broader and more indirect health related features ranging from the presence of nature (biophilia effect) to behavioral engagement and social capital and many others (safety, accessibility, access to water and food, quality of water and food, active lifestyle, etc.).

The crosscutting literature review as well as the analysis of case studies have highlighted the feasibility of implementing simple strategies to obtain great benefits but at the same time how complex strategies tend to be more capable of satisfying multiple benefits simultaneously. Nevertheless, such results must be tailored to specific contexts from a cultural, social, economic, climate, and microclimate point of view.

In this respect, the "setting" factor, conceived as site-specific design, is only made explicit in the Better Places Programme. The climatic/microclimatic aspects, which are specific to each location, significantly affect the relationship between building and environment. Taking this into account, "setting" should certainly be given greater importance, also by virtue of being a measurable parameter, therefore more suitable to objective post occupancy evaluation, thus to in-progress improvements. Aspects such as building shape and orientation, which differ in different latitudes/longitudes, significantly contribute to maximizing solar radiation and natural ventilation and consequently to improving thermal and visual comfort as well as indoor air quality. A correct interior layout of a building's functions, designed according to the time of use, optimizes the amount of natural daylight supply. Another considerable aspect is the building's form, defined as the ratio of dispersing surface area to heated volume. For example, in climates that tend to be cold, by using more compact shapes, therefore with a low surface area/volume ratio, heat dispersion toward the outdoor environment is limited thanks to a decision made already in the meta-design phase. Conversely, by adopting more articulated and permeable forms that increase the amount of dispersing surface area, the building will have a greater capacity to dissipate heat.

The case study review has also underlined how the indoor living, studying, and working conditions which embrace quality levels of comfort, individual lifestyles, social and community networks, actually affect, also the social, economic, and cultural status of the occupant. These determinants are all among the modifiable determinants susceptible to correction and transformation. The economic value produced by the improvement of some of the parameters can be divided into private and public sector value, ranging from metrics that influence personal financial outcomes, such as decreased healthcare costs or insurance premiums, to ones that relate to the sale or rental value of a property or development. Moreover, at a national scale one could mention also societal outcomes, such as decreased public health costs and increased economic prosperity, through to mortality rates and life expectancy. This reinforces the idea that the benefits of designing homes and neighborhoods for health and well-being can make a difference on many different levels.

Overall, healthy buildings pursue the physical and mental health of the human body under the premise of energy efficiency and environmental regeneration, within the broader approach of people-oriented design. It is likely that healthy buildings will become the new frontier of both the construction industry and institutional policies in the next decades. The improvement of existing and new buildings is a priority in tackling climate change and urbanization but equally a public health concern that requires respective social and equity priorities and that should therefore be of vital interest among policy-makers, the industry, architects and the public health community alike. In order to achieve this, future research could lead to the definition of qualitative indicators to measure all the listed building-related parameters.

References

1. Rydin, Y., Bleahu, A., Davies, M., Davila, J. D., Friel, S., De Grandis, G., Groce, N., Hallal, P. C., Hamilton, I., Howden-Chapman, P., et al. (2012). Shaping cities for health: Complexity and the planning of urban environments in the 21st century. *Lancet, 379*, 2079–2108.
2. United Nations, Department of Economic and Social Affairs, Population Division. (2019). *World urbanization prospects: The 2018 revision (ST/ESA/SER.A/420)*. United Nations.
3. World Health Organization. (2010). *Why urban health matters (No. WHO/WKC/WHD/2010.1)*. World Health Organization.
4. Fanger, O. (2006). What is IAQ? *Indoor Air, 16*(5), 328–334.
5. US Environmental Protection Agency. (1989). *Report to Congress on indoor air quality, volume II: Assessment and control of indoor air pollution*. Technical Report EPA/400/1-89/001C.
6. Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., et al. (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology, 11*(3), 231–252.
7. U.S. Environmental Protection Agency (EPA). (2013).*Questions about your community: Indoor air*. EPA New England. http://www.epa.gov/region1/communities/indoorair.html. Accessed 5 July 2022.
8. Spengler, J. D., MDMS, J. M. S., & DCIH, J. F. M. S. (2001). *Indoor air quality handbook*. McGraw-Hill Education.
9. World Health Organization. (2018). *WHO housing and health guidelines*.
10. Allen, J. G., Bernstein, A., Cao, X., Eitland, E., Flanigan, S., Gokhale, M., & Yin, J. (2017). *The 9 foundations of a healthy building*. School of Public Health.
11. WGBC. (2020). *Health & Wellbeing Framework six principles for a healthy, sustainable built environment - executive report better places for people*. World Green Building Council.
12. Higgins, S., Hall, E., Wall, K., et al. (2005). *The impact of school environments: A literature review*. Design Council, The Centre for Learning and Teaching, University of Newcastle.
13. Hammer, M. S., Swinburn, T. K., & Neitzel, R. L. (2014). Environmental noise pollution in the United States: Developing an effective public health response. *Environmental Health Perspectives, 122*(2), 115–119.
14. Heschong, L., Wright, R. L., & Okura, S. (2002). Daylighting impacts on human performance in school. *Journal of the Illuminating Engineering Society, 31*(2), 101–114.
15. Frumkin, H. (2003). Healthy places: Exploring the evidence. *American Journal of Public Health, 93*(9), 1451–1456.

16. Rosenfeld, L., Chew, G. L., Rudd, R., Emmons, K., Acosta, L., Perzanowski, M., & Acevedo-García, D. (2011). Are building-level characteristics associated with indoor allergens in the household? *Journal of Urban Health, 88*(1), 14–29.
17. Colton, M. D., MacNaughton, P., Vallarino, J., Kane, J., Bennett-Fripp, M., Spengler, J. D., & Adamkiewicz, G. (2014). Indoor air quality in green vs conventional multifamily low-income housing. *Environmental Science & Technology, 48*(14), 7833–7841.
18. Samet, J. M., & Eradze, G. R. (2000). Radon and lung cancer risk: Taking stock at the Millenium. *Environmental Health Perspectives, 108*(Suppl 4), 635–641.
19. Bornehag, C. G., & Nanberg, E. (2010). Phthalate exposure and asthma in children. *International Journal of Andrology, 33*(2), 333–345.
20. Wipfli, H., Avila-Tang, E., Navas-Acien, A., Kim, S., Onicescu, G., Yuan, J., et al. (2008). Secondhand smoke exposure among women and children: Evidence from 31 countries. *American Journal of Public Health, 98*(4), 672–679.
21. Dahlgren, G., & Whitehead, M. (1993). *Tackling inequalities in health: What can we learn from what has been tried*. Working paper prepared for the king's fund international seminar on tackling inequalities in health.
22. World Health Organization. (2014). *Global status report on non-communicable diseases 2014*. World Health Organization. https://apps.who.int/iris/handle/10665/148114
23. Asma, S., Lozano, R., Chatterji, S., Swaminathan, S., de Fátima Marinho, M., Yamamoto, N., et al. (2020). Monitoring the health-related Sustainable Development Goals: Lessons learned and recommendations for improved measurement. *The Lancet, 395*(10219), 240–246.
24. Gifford, B. (2015). *Linking workforce health to business performance metrics-strategies, challengers and opportunities*. Integrated Benefits Institute.
25. Lipset, S. M., Trow, M., & Coleman, J. (1956). *Union democracy* (1st ed.). Free Press.
26. Yin, R. K. (2003). *Case study research: Design and method* (1st ed.). SAGE.

Learning from Small Green Spaces: How Findings on Use and Perception Can Improve the Designing of Urban Experience

Leonardo Chiesi and Paolo Costa

1 Introduction

This essay analyzes the perception and use of Small Green Spaces (hereafter SGS) in the city of Florence, Italy. While there is no lack of research on social dynamics in large public parks and gardens (see, inter alia, [1–4]), empirically based studies of smaller urban green spaces are fewer (see, e.g., [5, 6]). This work investigates habitation of these spaces, in the broad sense of spontaneous appropriation of space by city users.

1.1 Small Green Spaces as Undervalued Urban Resource

The possibility of inserting plants within the urban context is receiving increasing attention due to its relevance to human health [7, 8]. Green areas have a profound impact on the lives of individuals and society at all scales. These effects manifest from the small scale of domestic or workspaces [9] to the large urban scale, where

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a correlation has been found between the presence of green areas and health and well-being of inhabitants [10]. Studies in dense metropolitan districts have shown, for example, a relationship between the presence of green areas close to the home (within a range of 1–3 km) and overall health [11].

SGS represent a promising way to increase the presence of greenery in urban areas because of their spatial granularity. Being of small size, they are highly adaptable to the scarce availability of space typical of dense urban environments. Furthermore, SGS can result from the opportunistic appropriation of urban spaces abandoned to themselves and overlooked by explicit planning intentions. SGS are often the planned output of the redesign of urban residual spaces, which derive from the imperfect integration of the urban fabric [12]. Given the scarcity of public space in dense cities, residual or vacant spaces are therefore an interesting asset, discussed in current debates within the architectural, urban design and planning domains. Such spaces command attention because they are a rare reserve of design and urban planning opportunities, considering that existing urban areas are, in general, highly saturated spaces and are subject to powerful interests that serve economic productivity and real estate investments [13]. In contrast, residual and vacant spaces might find their vocation in becoming public green spaces [14] and be construed as sites for the insertion of natural elements in the "mineral" environment of the city. In this, they allow the archetypal "urban park" to acquire yet another form, that of a "small green space" [15].

1.2 Three Classes of Opportunity in Space

To frame theoretically our data collection, analysis, and discussion of SGS habitation, we use a tripartite model of the interaction between people and space [16]. According to this model, we can construe physical space as a catalyst of opportunities for experience that are categorized in three distinct sets: opportunities to use the body, have an aesthetic experience, and manipulate signs to access meaning.

First, we inhabit space with our bodies. We move in space, place ourselves, and express ourselves in a continuous proxemic discourse. Space is, from the perspective of the body, a repository of affordances, i.e., opportunities for action [17]. Affordances have two dominant attributes: proxemic and relational. At the immediate scale of the space that surrounds the body, the space allows a wide range of possibilities, from those offered by a small touch screen on a phone on which fingers make micro movements, to those of a well-designed bench on which the body comfortably rests in an urban park. Proxemic affordances are a set of opportunities that imply direct bodily contact and that can be realized through the plasticity of the body, thus forming the so-called extended-body, a system made of the mutual integration of the body proper and the object. Affordances may also provide a framework for engaging in relationships: opportunities for the body embedded in space may favor or inhibit contact between bodies, speaking, looking at each other, etc. These relational qualities of affordances enable the regulation of interpersonal relationships and are realized in pairs or in group, or even in solitude when privacy is preferred. As such, affordances may be construed as socio-fugal, when they inhibit relationships, and socio-petal when they favor relationships.

Secondly, space offers opportunities for sensorial experience. We might say that we "taste" space through our senses. Space penetrates us through sensorial channels and activates highly diversified internal processes. Aesthetic experience is a universal category of human experience, and the physical environment that surrounds the body constitutes one primary opportunity for aesthetic appreciation, contrary to the common knowledge that associates aesthetic experience solely with works of art, especially painting and sculpture. Quotidian aesthetic experience of space is continuous, whereas works of art are discrete, and emerge from the ordinary into the extraordinary; it is spontaneous, i.e., disengaged from critical discourse and reception; and it is interested, in that it manifests with an affective investment that attracts or repels us. This kind of aesthetic experience is frequently elicited by the exposure to the natural environment, as nature has been the primary source of sensorial stimuli for the most part of human evolution. The presence of greenery in modern urban life is therefore an important component of aesthetic experience at large [18].

Lastly, physical space is the support on which signs materialize. A sign is "everything which can be taken as significantly substituting for something else" [19], and space offers opportunities, on the one hand, to inscribe signs that refer to meanings and, on the other, to associate meanings to signs inscribed by others. These opportunities activate our capacity of identifying links between the tangible world of signs and the intangible mental world of meanings. There are two categories of signs inscribed in physical space. There are signs inscribed in space during the design process (conception and construction) by designers. Then there are signs that users inscribe in the space during habitation: these are additions that add communicative content while not modifying affordances [16]. In the urban context, a myriad of signs are constantly interpreted and connected with meanings, consciously or not. This dual interplay between signs and meanings shapes the experience of place in subtle ways as it deals with the imaginary and symbolic, and yet its effects are remarkable in determining the overall experiential content.

2 Materials and Methods

2.1 Case Studies

A set of ten SGS was selected from 66 SGS evenly distributed in the city of Florence. Eight spaces are in the historical center or at its edges; two small plazas, although outside of it and with less greenery, were included to allow comparison and contrast with the rest of the sample. The ten SGS belong to different kinds of public spaces. Three are small public gardens; one is a wilder green area on the riverbanks of the city river Arno; three are paved squares that include trees or other green elements;

the last three are green spaces that open up on the side of streets. They all vary in size and proportion of green surface. To allow comparison with similar studies (see, e.g., [5]), the selected SGS are not larger than 5600 m^2; they have at least some vegetation (all have trees and in six cases their green area is at least half of the total area); they have their own entrance or distinguishable boundaries which separate them from the surrounding public space.

2.2 The Research Design

The research design employed a mixed method strategy, involving four data production techniques. First, unstructured observation and in-depth interviews with users were performed; then, structured observation sessions and a questionnaire allowed a quantitative description of users and their practices. Fifty in-depth interviews were conducted with SGS users in the spring of 2016, for a total of 30 hours of conversation. Then, 430 users were surveyed with questionnaires administered directly in the selected SGS. The samples of both in-depth interviews and questionnaires were stratified by gender and age, resulting in a balanced distribution.

Given the size of the sample, an analysis of the differences between spaces would not have enough statistical significance and was not conducted. For a wider description of the case studies and the sample, an extensive illustration of the analysis and the results, and for tables, photos and quotes from the interviews, see [20].

3 Results

3.1 Patterns of Use

Frequency and duration. The first key factor emerging from questionnaires is continuity of SGS use. This continuity is, first, throughout the year, as over half of the respondents use SGS in all seasons. The climatic factor is less relevant for SGS in our sample than reported by other studies about larger green spaces and urban parks, at least in places where seasons are different enough. Yearlong continuity is coupled with frequency of use on a shorter-term basis. Frequency is at least daily for more than 40% of users, again in a much higher proportion than for urban parks and larger green spaces, where around 50% of users go less than once or twice a month [1]. The percentage of users visiting SGS more than once a week is around 75%, and this cumulative proportion rises to almost 95% when including users who visit SGS two or three times a month. Use is also constant on a daily and weekly basis. Almost all respondents (90%) visit SGS on working days and 60% of respondents go there during the weekend, whereas larger parks are visited more often on weekends than weekdays. Daily SGS use is balanced between morning and afternoon. The analysis across generations shows that the elderly have the most intense use of SGS, as they go there daily in a higher proportion than average. Use throughout the day is also linked to age. Although people above 50 years old go to SGS at any time of the day, in the morning they are more present than other age groups, whereas people under 30 go there more at lunchtime and in the afternoon. In the evening, attendance is generationally more balanced, except for the 51–70 age group, whose presence is lower than average. The average time users spend in SGS is around 30 minutes, with most visits lasting between 10 and 30 minutes. When visits are longer than 30 minutes, they tend to last one entire hour. These data show that people go to the SGS more often and for a shorter time than it usually happens for larger green spaces [2].

Getting to and from SGS. The mobility data show that SGS are frequently visited but are located in the proximity of other settings where a significant part of their life takes place. Home is by far the predominant place users come from when they get to SGS, and is also the most common destination upon leaving. Compared to larger parks, SGS are less a final destination than an intermediate one. On average, users take only nine and a half minutes to get to SGS. For most respondents, this duration is even shorter, as mode and median durations are shorter than average (respectively, around 6 and 5 minutes). To get to SGS, walking is prevalent in all age groups, and almost exclusively for those over 70 years old. Other means of transportation, especially bicycles, are more common for younger users. These data suggest that the SGS use is a neighborhood experience that occurs mainly in proximity with the residence. As it was clear in many in-depth interviews, this proximity is a defining accessibility factor for specific user categories, such as the elderly.

3.2 Practices

Focusing on activities within SGS, respondents to the questionnaire reported a wide variety of practices performed there, often during the same visit. The two most performed activities in SGS are those connected with socialization and the enjoyment of the outdoors, that were mentioned, respectively, by two-thirds of the sample and almost half of it. The preeminence of relational experiences in SGS is confirmed across all age groups, and in particular in the younger and elder generations. In SGS, users spend their time mainly with friends, partners, and relatives, almost in all age groups and in particular for younger users. Around a fifth of the sample, however, use SGS alone.

Activities related to pets are performed by a quarter of respondents. Observation confirmed that walking and playing with dogs also promotes serendipitous social encounters, especially with other dog owners. While in large parks dog owners generally have a different use profile than other users, in SGS dog owners' typical attendance is more similar to that of other users. Smoking is a common activity in SGS for about a third of users. This proportion being higher than the average rate of Italian smokers suggests that SGS are perceived to have less restrictions than other public spaces, where smoking is often forbidden by law. Other activities performed in SGS involve the use of electronic devices or, more generally, objects. Mobile phones, for example, are used in SGS by one-quarter of the respondents. Although our data do not allow an in-depth analysis on the uses of these devices, observation showed that their negative impact on sociality is reduced in this context. This is consistent with research showing that mobile phone use is less common in public spaces where sociality is intense. Reading is carried out in slightly different proportions by different age and gender groups, also depending on the kind of media, respectively, newspapers, magazines or books. Another individual practice performed with devices is listening to music, mostly with mobile phones. Listening to music on loudspeakers, as a group practice, is more common in larger spaces than in SGS.

Conflicts of practices and users. Intense and varied use in limited space can produce conflicts among different user groups. Young users often seek opportunities to play, move about, and have fun. These practices, however, are sometimes feared by the elderly. Dogs' presence can be seen as problematic by other users, such as young people wanting to play or those who go to SGS with children. Furthermore, observation showed that high accessibility and low level of control of SGS are perceived as desirable features by the homeless, who often use SGS as shelters. This informal use of SGS is generally accepted by users. Conflicts can be seen as problematic by some user groups, but they rarely prevent the use of SGS. Conflicts and informal uses generating them are side effects of two features that general users appreciate in SGS: the wide range of practices that SGS host in relatively small spaces, and the sense of loose social control that users perceive.

3.3 Opportunities for Social Activation

Social activities, such as meeting and being with others, are the most performed activities in SGS that are perceived as ideal settings for this purpose. Observations showed how SGS promote social interactions, and this emerged when experiences in SGS are analyzed through the tripartite model of interaction between people and space that we introduced in Sect. 1.2. Observing proxemic and relational affordances—the opportunities for action with the body—illuminates the dynamics of social practices. In SGS, proxemic affordances are those that allow users to relate their bodies to the spaces around them, sit, lean, or stretch out, not only on designed devices, such as benches, walls, or fences, but also on natural elements, such as grass, trees, or stones. Relational affordances are the spatial opportunities that allow people to experience a variety of social relations: interacting with others, talking with friends or strangers, playing or watching children or others play, but also spending time by themselves, to read, think, or meditate, in more socio-fugal areas of SGS. Often proxemic and relational affordances overlap, when the postures afforded by the proxemic opportunities of space also affect social relations, allowing different degrees of interaction.

Interviews further elucidate how SGS users are sensitive to designed opportunities for interpersonal relations. Seating options are essential to SGS users. Additional seating is the second most requested feature among all changes users would like to see in their SGS. The familiarity of users with SGS allows them to understand how their spatial opportunities affect sociality and their chances to have different kinds of relational experiences, even serendipitous ones. User's spatial awareness is quite accurate and in some cases they understand how proxemic and relational affordances are connected, resulting in spaces that allow different degrees of social relations. Observations showed several clues of appropriation of spaces, such as benches that were repositioned by users in a more socio-petal setting. These episodes of self-redesign are examples of social production of space that further demonstrate how relational needs are strongly felt in SGS.

3.4 Other Opportunities and Perceptions

A variety of opportunities perceived in SGS have a prominent role in shaping both the sensorial and semantic experiences of users. Firstly, respondents often appreciated how the perceptions available in the SGS environment promote positive states of mind that allow relaxation and meditation. Even if the effects on health and well-being usually occur without people being aware of them, some respondents explicitly referred to the effects of SGS attendance on their health. Secondly, SGS are perceived and used as convenient *escapes*, to interrupt the stressful patterns of daily life that also affect health, and to cope with the hyper-stimulation and the chaotic character of most public spaces. Such experiences can be made daily or on special events, socially or in solitude. SGS provide access to a sensorial experience that strongly contrasts with the chaotic characters of other public spaces. Continuity of SGS use (see Sect. 3.1) allows users to have sensorial experiences making them appreciate the changing natural features throughout the entire year. Such natural features and greenery are relevant in shaping users' overall positive experience of SGS, and this appreciation encompasses different aspects of their relationship with the environment that relate to the senses and the world of meanings. These perceptions are consistent with data collected through the questionnaire: additional greenery (in various forms: trees, shrubbery, flowers, etc.) is by far the most mentioned request (43%) users made when asked what they would like to change in their SGS. This further explains how important natural features are for users, and also how such features concur to create opportunities for users that include every category of spatial habitation.

4 Discussion

4.1 Functional Indetermination and Non-normativity as Features Shaping SGS Experience

Data gathered through in-depth interviews and observations show that two qualities shape more than others the social experience of users in SGS: functional indetermination and non-normativity.

Functional indetermination. The wide range of practices performed in SGS is promoted by their functional indetermination, in that SGS do not direct users toward rigidly predefined functions. An example about seating will clarify this concept. While most users sit on benches, interacting with others or in solitude, others prefer to perform the same practice in different ways, e.g., sitting on low walls, railings and fences, large stones, or on grass. And the same grass also affords other practices, such as playing, doing physical activities, or just lying down and resting. In general, SGS natural elements such as trees, trunks, lawns, hedges, and rocks afford a higher degree of functional indetermination than designed devices, stimulating undirected social production of space and, hence, a stronger appropriation of SGS. As shown, users value a space that affords multiple opportunities, such as, for example, being in solitude and interacting with others. However, the range of possible practices is also widened by the positive sensorial experience offered by SGS, as affordances and opportunities for the senses are often intertwined.

Non-normativity. While functional indetermination was revealed mainly through observation, in-depth interviews allowed us to discover how non-normativity of SGS is valued by users. As mentioned, SGS are often perceived as spaces of refuge from everyday life. This perception is reinforced by the fact that users construe SGS as places that allow for a set of negative liberties from social institutions (e.g., family, market, and government) which exercise regulative control in many areas of present-day city life. SGS suitability for sociality is thus connected to the lack of restrictions and spatial boundaries that are instead common in many other environments, public, semi-public, or private, such as homes, community centers, and shopping malls. The home, for instance, is a place where the social control of parents and families is exercised on teenager, a control that they don't feel in SGS. Interviews exemplified various social representations of non-normativity. For example, the higher rate of smokers in SGS than in the general population, in a social context where smoking is forbidden in most public spaces, can be interpreted as an effect of the perceived non-normativity of SGS. Similarly, informal practices performed by the homeless in SGS result from non-normativity: as in many other city centers, in Florence such practices are carefully controlled by the administration, and SGS remains one of the few public spaces where the homeless can find shelter. In conclusion, this reduced pressure from the social control commonly experienced elsewhere is valued by users, who enjoy the freedom of not having to respond to any authority that presides over space. The public nature of SGS makes them fully accessible. As a result, people can meet and spend time there at no cost, differently from, for example, sitting in a cafe. This makes gatherings free from time constraints, so users often do not need to plan ahead to meet others, and only rely on the reasonable expectation there will be someone to socialize with.

An open-ended experience. High degree of functional indetermination and non-normativity allow for a range of open-ended experiences that affect all practices in SGS, including the activities connected with socialization, the most frequent in SGS. Serendipitous interaction with strangers, so common and appreciated among some user groups, is one of the social experiences promoted by this open-endedness. In a way, and especially for elders, SGS recall what squares used to be in the past, indeterminate venues offering opportunities for sociality and for other practices to a wide range of users. Both functional indetermination and non-normativity mutually contribute to the open-endedness of users' experiences in SGS: with functional indetermination, users are less driven to perform specific activities, and this leads to a heightened sense of freedom. At the same time, a perceived non-normativity makes users feel more open to explore the wide experiential opportunities afforded by functional indetermination.

4.2 SGS and the City: Contrasting with Other Public Spaces

SGS functional indetermination and non-normativity have implications that extend to the urban scale. The relevance of these two qualities is revealed if contrasted with what is happening to public spaces in large contemporary cities, where since the 1990s there has been an extensive commodification and privatization of urban spaces. Such transformations have been leading to an overall reduction of the diversity, vitality, and authenticity of the experiences that the urban environment traditionally has offered. In this framework, public spaces are increasingly shaped according to a restricted set of predictable and homogenous experiential themes that follow dominant economic trends and the corresponding social and cultural narratives. For example, in the last decades, Florence has adopted an urban growth model that is increasingly centered on tourism, that more recently has produced the typical negative effects of touristification and overtourism [21]. As in other European historic cities, this process has increased short-term rentals and has produced gentrification, de facto expelling most long-term residents from the city center [22]. SGS users referred to these phenomena, criticizing a compression of public use of spaces and remarking on how many streets and squares in Florence have lost the accessibility and indetermination they consider as essential qualities of public spaces. Several respondents mentioned the process of touristification as an impacting transformation of the city. What is relevant is that users contrast these changes and the decay of the values of urbanity they observe in many public spaces with SGS and their open-endedness. This reveals that users perceive SGS as spared from the transformations that affect other urban spaces, and that open-endedness is an appreciated feature of SGS.

5 Conclusion

This study highlights the value of Small Green Spaces in urban everyday life. We argue that the mixed method approach allows the understanding of patterns of use, perceptions, and practices of appropriation of space in SGS. The theoretical framework of the three classes of opportunities in space (Sect. 1.2) helps deconstruct the complexity of habitation from the point of view of users. We discussed specific features that frame SGS as a setting for urban practices and perceptions that are different from those of other urban settings, and contrasted SGS with larger green spaces and city parks. First, habitation of SGS is continuous on a yearly, weekly, and daily basis. Visits are on average shorter and more frequent than in larger parks, and SGS are a persistent scenario of users' daily life. A wide set of data also contributes to define SGS use as strongly dependent on their proximity. SGS are experienced as a neighborhood opportunity near users' most frequented urban settings, and specifically their homes. Such proximity contributes to continuity of use and is a requirement for access of specific user groups, such as the elderly.

SGS allow access to a variety of practices and sensorial experiences. This set of experiences, often mediated by natural features, is highly appreciated by users, who often find there an escape from stress and urban overstimulation, and restorative opportunities for their physical and mental health. Proximity allows continuous availability of SGS on a short-term basis. Thanks to this availability, the relationship with nature becomes part of users' urban everyday life, thus not remaining confined to dislocated experiences that happen "not here, but somewhere, and once in a while," as with urban parks or the countryside. SGS features do not seem to be significantly related to gender or age. On the contrary, all user groups show a generalized approval for the diversity of opportunities that SGS offer.

Conflicts found in SGS are collateral effects of features that are valued by users. Some practices generate conflict because of the limited size of SGS, a feature that, however, allows their proximate and widespread availability in the city. These types of conflicts in SGS could be regulated with a variety of strategies. Policies based on time scheduling of potentially conflicting activities, for example, could alleviate the intensity of such conflicts. Another strategy could be to plan a highly distributed network of proximate SGS, dispersing conflicting opportunities in different SGS that are close enough to each other. This reinforced proximity would increase the accessibility of a neighborhood experience of SGS. It is essential, however, that such strategies preserve a significant degree of functional indetermination in each SGS. We have also highlighted another type of conflict arising from informal practices performed by the homeless. As seen, this informality can be interpreted as another effect—although problematic—of the non-normativity that is so valued by users. Addressing these tensions requires a multidimensional approach that goes beyond SGS management. Such strategies, once again, should not interfere with the sense of freedom and non-normativity users have shown to appreciate in SGS.

The specificity of SGS patterns of use calls for further investigation to better qualify the differences with other urban green spaces, specifically large urban parks. Many published studies still refer to equivocally defined green spaces, where vegetation is present at significantly different degrees. Addressing such specificity would also help define a further role of SGS in the urban environment. The notable level of sociality we found in SGS may have an impact on social cohesion, a notion that refers to the strength of social ties in a community. The presence of urban green spaces has been already associated with social cohesion, as the positive and frequent interactions taking place there affect some of its dimensions, such as place attachment and social capital. Consequently, urban green spaces have been construed as a resource to contrast the crisis of social cohesion of contemporary western cities. This connection could be further investigated in relation with SGS, to explore the direct effect on social cohesion. We believe that the constructs of functional indetermination and non-normativity could inform further research on the connection between SGS and social cohesion. We hypothesize that social cohesion is more strongly supported in SGS with higher degrees of functional indetermination and non-normativity, where experiential openness is significant. The confirmation of this hypothesis would open new lines of research with implications on the design, planning, and management of SGS.

In conclusion, we argue that SGS are an undervalued urban setting with remarkable positive potential for dense cities, where the lack of public space can be partially relieved by converting residual spaces. Redesigning vacant spaces as Small Green Spaces may create new places of appreciated opportunities by inhabitants, places where some of the most spontaneous and undirected practices of urban life, such as socialization, can coalesce. We believe it is worth continuing to investigate Small Green Spaces. These urban spaces represent a valuable resource in an era of large-scale compression of the public sphere of cities, and an exemplary resource to extend the accessibility of an all-round experience of urbanity.

References

1. Özgüner, H. (2011). Cultural differences in attitudes towards urban parks and green spaces. *Landscape Research, 36*(5), 599–620.
2. Kothencz, G., & Blaschke, T. (2017). Urban parks: Visitors' perceptions versus spatial indicators. *Land Use Policy, 64*, 233–244.
3. Mak, B. K. L., & Jim, C. Y. (2019). Linking park users' socio-demographic characteristics and visit-related preferences to improve urban parks. *Cities, 92*, 97–111.
4. Gaikwad, A., & Shinde, K. (2019). Use of parks by older persons and perceived health benefits: A developing country context. *Cities, 84*, 134–142.
5. Peschardt, K. K., Schipperijn, J., & Stigsdotter, U. K. (2012). Use of small public urban green spaces (SPUGS). *Urban Forestry & Urban Greening, 11*(3), 235–244.

6. Macintyre, V. G., et al. (2019). “I would never come here because I’ve got my own garden”: Older adults’ perceptions of small urban green spaces. *International Journal of Environmental Research and Public Health, 16*(11), 1994.
7. Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Frontiers in Psychology, 6*.
8. Rojas-Rueda, D., et al. (2019). Green spaces and mortality: A systematic review and meta-analysis of cohort studies. *The Lancet Planetary Health, 3*(11), e469–e477.
9. Lee, K. E., et al. (2015). 40-second green roof views sustain attention: The role of micro-breaks in attention restoration. *Journal of Environmental Psychology, 42*, 182–189.
10. Kardan, O., et al. (2015). Neighborhood greenspace and health in a large urban center. *Scientific Reports, 5*, 11610.
11. Li, Q. (2010). Effect of forest bathing trips on human immune function. *Environmental Health and Preventive Medicine, 15*(1), 9–17.
12. Piccinno, G., & Lega, E. (2013). Spatial design for new typologies of places: In-between urban spaces. In B. L. Rogers & A. Sugiyama (Eds.), *Space and place: Diversity in reality, imagination, and representation* (pp. 41–44). Brill.
13. Anderson, E. C., & Minor, E. S. (2017). Vacant lots: An underexplored resource for ecological and social benefits in cities. *Urban Forestry & Urban Greening, 21*, 146–152.
14. Pearsall, H., & Lucas, S. (2014). Vacant land: The new urban green? *Cities, 40*, 121–123.
15. Cranz, G., & Boland, M. (2004). Defining the sustainable park: A fifth model for urban parks. *Landscape Journal, 23*(2), 102–120.
16. Chiesi, L. (2016). Territoriality as appropriation of space. How “engaging with space” frames sociality. In J. Dessein, E. Battaglini, & L. Horlings (Eds.), *Cultural sustainability and regional development: Theories and practices of territorialisation* (pp. 146–161). Routledge.
17. Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin.
18. Brady, E., & Prior, J. (2020). Environmental aesthetics: A synthetic review. *People and Nature, 2*(2), 254–266.
19. Eco, U. (1976). *A theory of semiotics*. Indiana University Press.
20. Chiesi, L., & Costa, P. (2022). Small green spaces in dense cities: An exploratory study of perception and use in Florence, Italy. *Sustainability, 14*(7), 4105.
21. Veríssimo, M., Moraes, M., Breda, Z., Guizi, A., & Costa, C. (2020). Overtourism and tourismphobia: A systematic literature review. *Tourism: An International Interdisciplinary Journal, 68*(2), 156–169.
22. Oskam, J. A. (2020). Commodification of the ‘local’ in urban tourism: The Airbnb contradiction. In J. A. Oskam (Ed.), *The overtourism debate* (pp. 151–170). Emerald.

New Regeneration Scenarios to Improve the Livability in Villages

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1 Living in Proximity: Small Villages as Alternative Housing Urban Models

The year 2009 represented an important moment in the history of urbanization: the resident population in cities exceeded that living in the countryside, 3.42 billion against 3.21 [1]. From that date, the progressive depopulation of the smaller towns and countryside in favor of the big cities seems to be irreversible. On the one hand, cities have grown in size by developing suburbs to meet the growing demand for housing; on the other hand, these new settlement models have proved socially fragile, offering worse living standards than small towns, due to the scarcity of public services offered and ever-increasing distances. The same COVID-19 pandemic has highlighted the fragility of cities, reviving the discussion on small-medium cities as the most suitable places to deal with possible new health emergencies and the economic crisis. In the European Union, rural and intermediate areas make up 88% of the territory, and in Italy internal, peripheral, rural, mountain municipalities of smaller demographic dimensions (there are 5627 villages) cover 54.1% of the total area of the peninsula; they present two million unused homes. These small municipalities now offer an effective option to meet the new needs of citizens, thanks to both a less hectic and more human-sized living environment and the availability of affordable housing and a more balanced relationship with nature [2].

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Community and individual member state policies have for some time been oriented toward objectives of environmental regeneration, technological innovation, and protection of cultural heritage and small municipalities. At the national level, there are numerous actions to support the promotion and protection of the wealth of the territory and local communities, enhancing their natural and cultural resources, creating new employment circuits and new opportunities, which have already been launched in the pre-COVID phase. The National Strategy for Internal Areas (NSIA) represents an innovative national policy of development and territorial cohesion that aims to counter the "demographic hemorrhage" of small towns in Italy, through funding that has grown over the years, up to the most recent support funds for marginal municipalities (DPCM 30 September 2021), economic activities (DPCM 24 September 2020) and the conservation of the natural heritage of small towns (D.L.n.120 of 8 September 2021, converted into Law 155 of 8 November 2021). A road, that of incentives, shared by many local administrations in Italy and Spain, which offer new residents monthly contributions (from 100 euros per month to the new residents of Xesta in Spain to the 500/700 of Civita di Bagnoregio, or of the villages of Molise in Italy, to 3000 euros to take up residence in Asturias in Spain) or low-cost rentals (from 0 to 120 euros in the Municipality of Bormida in Cuenca region).

The EU has provided the definition of "smart villages" meaning a small municipality, the characteristics of which range from the participation of local communities, the use of digital tools as fundamental elements for cooperation with other communities for improving access to services, development of short food supply chains and the development of renewable energy sources. The concept of "smart villages" is making its way onto the rural development agenda, coinciding with the current reform process of the Common Agricultural Policy (CAP), which includes among its key aspects a new implementation model based on the development of a CAP strategic plan by each member state [3, 4].

The growing awareness that the territory is designed on a small scale, and that it is not the size that improves the quality of what we have, highlights the need to bring together disciplinary and institutional sectors toward territorial governance policies capable of dealing synergistically with the sustainable development of the settlement system, the efficiency of the infrastructural system, the protection of the historical-cultural heritage, the regeneration of public space, the enhancement of the landscape-environmental system of small towns. These synergies are the only resources to which a country in inland areas can anchor itself to try to reverse the processes of territorial abandonment and rebalance the relationship with the city [5] to reconstruct the interrupted synergies between territory, environment, and production [6], to define a new development vision based on the interdependence and cooperation of different territorial systems [7].

However, it is urgent to define actions, tools, implementation mechanisms, parameters, and indicators capable of concretely supporting the adaptation of small villages to new urban inhabitants who aspire to healthier lifestyles, sustainable housing models supported by geographical accessibility (reachability) and spatial accessibility, and overcoming the *digital divide*.

The research[1] proposes to develop the ecological-digital transition on the multi-scalar level of public spaces and buildings of the small villages of the internal areas, in terms of regeneration and redevelopment in a holistic-circular key, through adaptive interventions applied to the building stock, to open spaces, and infrastructures—of tangible and intangible flows—aimed at increasing climate mitigation and carbon neutrality, the consequent conditions of well-being and livability and increasing the capacity for "preparedness." The research goal is to development of a framework of strategies and actions, structured on project measures and related technological systems, which allows the organization of interventions at different scales, characterized by replicability and adaptability to other contexts. In particular, the research project is divided into thematic axes divided into two levels: urban scale, building and component scale. The review and systematization of the literature led to the identification of a framework of adaptive/circular strategies at the single component, building and public space scales, and to the verification of the model in a design experiment on a small town in Spain.

2 Public Space Strategies: From Universal Design to Active Design

This level concerns the public space and its social and environmental dimension and is characterized by actions that reactivate the traditional alliance between human and natural components as co-acting forces in order to obtain a rebalancing between densification and ecologization. Certainly in recent years, an increased awareness of the diversity of human behavior has contributed to a greater focus on the design of the built environment [8] and the definition of urban design criteria and guidelines that are increasingly attentive to an understanding of "human scale" [9], understood as the ability of physical elements to dialogue with the size and proportions of human beings (inclusive and Universal Design Approach). The COVID-19 pandemic highlighted how this "user-inclusive approach in space" affects not only the dimensional/physical/spatial component but also that of social networks, especially for the most fragile people (elderly and children) forced during the pandemic to a condition of isolation/solitude [10] and exclusion from socially beneficial activities. Google data compiled by Citymetric show that more people, especially the elderly, started visiting parks as countries relaxed restrictions. A recent survey by Natural

[1] The paper was written in the context of the project "new regeneration scenarios to improve the livability in Middle /Small Sized Cities." Project started in 2021 with the activity of visiting professor, supported by University of Seville, Spain, on the topic "Regeneración de núcleos rurales deshabitados, desde el punto de vista de su inclusión y accesibilidad, mediante simulaciones a través de la tecnología BIM." Although the paper must be considered the product of a close collaboration among the four authors, Sects. 2 and 3 should be especially attributed to C.Cellucci, Sect. 4 to M. R. Chaza and Fernando Rico. The introduction and the conclusions are obviously shared.

England revealed that the vast majority of adults (89%) in the UK agree that green and natural spaces are places that promote mental health and well-being.

Precisely in small towns, contexts in which *human health–planetary health* relations express their effects more than anywhere else, it is necessary to intercept new solutions and rules that think about:

- Physical characteristics of the spatial and technological building system that can support opportunities for social interaction [11], such as top-down initiatives, aimed at ensuring proximity between housing and services (workspaces with technological devices, recreational spaces, parks, etc.).
- Ways of using the village, through solutions that satisfy both the need for urban space/equipment (user-space-objects interaction), and of greater sociability (user-user interaction), and social distancing measures to contain the spread of this and future pandemics, with specific attention to different profiles of the users themselves and the disabling factors that the distancing and the use of safety devices can entail.

It will also be necessary to pay attention to some characteristics of the built environment that can support opportunities for social inclusion/interaction [12]. At the public space level, the main thematic axes of research concern actions of:

- Nature-based solutions aimed at improving the health of ecosystems and resilience to change using circular actions of mitigation, adaptation, and restoration such as the integration of greenery (green infrastructure, field operations, synthetic surfaces) and the management of the water cycle (holistic systems Water Sensitive Urban Design) in the built environment.
- Solutions for pedestrian/cycle mobility to make small towns attractive/comfortable and redirect pedestrian mobility in an active/inclusive sense (in accordance with the international framework of best practices on "10 minutes districts") with repercussions on the well-being people conditions.
- Community-based solutions of co-design and co-management of collective spaces (Empowerment by Design solutions) such as those implemented in the projects of C40 CITIES, D.I.Y. Urbanism, Tattica Urbanism, Pop-up urbanism, Guerrilla Urbanism, City Repair, Parking-day.

Since the state of psycho-physical well-being of the user is indirectly influenced by the morphological-typological specificities that characterize the places where we live, able to affect negatively or positively on the health status of the population and the adoption of healthy lifestyles, the design of open spaces and urban routes, is an opportunity for the design of open spaces as places that enable more active lifestyles.

This approach to public space design can have repercussions on environmental health determinants (air pollution, noise and light, waste production, presence of green areas, direct consequences on the increase of the "urban heat island" effect) and indirectly on behavioral determinants, the so-called "lifestyles" (walking instead of driving, the use of the stairs instead of the elevator, socializing instead of isolating).

Several project experiences (The Pulse Park and Odense Training Park in Denmark; the Central Green Park in Philadelphia; the Luis Bruñuel Metropolitan Water Park in Zaragoza; the Ready. Steady. Go! installation in Graz; the Soperkilen Master Plan in Copenhagen; The High Line in New York) consider physical space in relation to human senses (including proprioception and the vestibular system) aware of their ability to influence our active experience of movement. There are a number of environmental attributes that are considered to be of moderate to high importance in achieving higher rates of active mobility. These attributes include aesthetics, distance, greenery, traffic, access, open spaces, services, safety, the pleasantness of the experience, the age of the buildings, the practicality of the environment, infrastructures, the convenience of moving, the quality of the neighborhood, the offer of diversified services, usability, and street lighting to decrease the crime rate [13]. The definition of the design features and services provided by spaces and routes for public use seems relevant in order to encourage or, on the contrary, discourage, or even prevent, an active life, conducted in full autonomy [14]. In particular, the evidence shows how attractiveness, pleasantness, and ease of orientation in outdoor spaces and green areas can be strongly discriminating for the desired adoption of lifestyles based on a regular physical activity carried out not only in the gym but outdoors on paths and spaces designed to encourage movement and physical exercise.

The user-space relationship and its active use presuppose qualitative and quantitative considerations on the presence of:

- Urban spaces for physical activity, the quality of which depends not only on usability and on the conformational-dimensional relationship (accessible, inclusive space) but also on the capacity of the space to be an "experiential reality," which interacts/stimulates physical, sensory, cognitive user characteristics.
- Urban equipment conformed and positioned to improve / enhance users' functions and enable their residual capacities (e.g., Health Loop Gym, Lappset sport, Leopold Tree Di Metalco, Capeston Fitness).

3 Building Stock Strategies for a Circular Regeneration

This level concerns the building and its functional / architectural dimension and is characterized by actions aimed at increasing the duration of the building product through solutions for the recycling of the housing stock in terms of adaptive customization, i.e., personalization of spaces, equipment, furnishings, and elements through a continuous cycle of upgrades / downgrades. It follows that the value of the built space loses its centrality as an unchangeable artifact capable of responding to standardized needs and necessarily limited to the short / medium term in order to acquire value from the ability to guarantee, in the long term, progressive spatial and technological performance adaptations and evolutions. The implementation of adaptability can be expressed at the scale of the building through spatial and technological options that consider the relationships of the requirements relating to the morphological-distributive characteristics (versatility, convertibility of space, evolution, expandability, extensibility), system integration and construction (reversibility of partition / furniture systems in a logic of maintainability, disassembly, modularity / composability) with the circularity sub-requirements relating to products / components (Refuse, Rethink, Reduce), to regenerative processes (Reuse, Repair, Refurbish, Remanufacture, Repurpose) and smart applications (Recycle, Recover).

This level includes actions aimed at the choice of materials and assembly systems capable of giving the artifacts adaptive behaviors through the reactivity of the technical elements of which they are made with respect to the variability of external stresses (environmental vulnerability) and / or internal (variability of the existential framework). This level poses an important challenge to the project concerning the relationship between the material dimension and the design. The latter should evaluate individual components not only from the perspective of technical and environmental performance related to the contingent but also to the ability to respond to stressful conditions over time. The research carried out in recent years on the material side is emblematic: from bio-based systems inspired by biological systems (biodegradable, compostable, recyclable) with "resilient capacity" in terms of optimization of the production process with respect to the consumption of resources and the impacts produced [15], react-based integrated with nanotechnologies functional to the activation of self-regulation processes (Phase Change Material) that reduce dependence on external maintenance / energy sources [16].

At the building and component level, the main thematic axes of research concern actions of:

- Energy transition for the reduction of energy needs and the consequent maximization of production from renewable sources, through the research and systemization of Nearly Zero Energy, Net Zero Energy, Positive Energy Village models.
- Adaptive customization of the building and housing through the study of envelope models capable of improving the morphological-distributive characteristics (implementing the requirements of versatility, space convertibility, evolution, expandability, extensibility, inclusiveness), plant integration and constructive (implementing the reversibility requirements of partition / furniture systems in a logic of maintainability, disassembly, modularity / composability).
- Design for disassembling for the adaptability of the construction system and the technical elements to external/internal stresses in terms of ease of maintenance, disassembly, repairability.
- Circularity relating to products/components (Refuse, Rethink, Reduce), to regenerative processes (Reuse, Repair, Refurbish, Remanufacture, Repurpose) and smart applications (Recycle, Recover).
- Technological updating, through the use of noninvasive technologies with little (or no) impact on the overall appearance of the building and its context but in support of teleworking and digitalization, digital education and training.

- Materials and techniques deeply rooted in the local building culture, and the reuse of the original typology of the existing buildings that, on the one hand, ensure the preservation of the heritage and, on the other hand, the identity characteristics of the place.

4 Methodology to Transfer of the Theoretical Model to a Case Study

The methodology proposed to implement the proposed strategies is based on the use of the TLS (Terrestrial Laser Scanner) system, with which a complete point cloud is obtained that serves as a basis for the verification of the possible existing planimetry, or the realization of the same, with a high degree of geometric accuracy. It is a methodology of which there is abundant scientific literature [17–20], although mostly focused on singular historical buildings [21–23], etc.

Having a real and updated planimetry, or the three-dimensional model made in BIM (Building Information Modelling) environments based on the point cloud, will facilitate the graphic and morphological analysis in the two phases proposed:

- Verification of the characteristics of the built environment and its urban scale.
- Adequacy of the scale adaptability of the building in its environment, and the implementation of components, materials, and techniques capable of providing buildings with adaptive behaviors (Fig. 1).

By importing the point cloud into a BIM system, such as Autodesk's Revit, we can observe the characteristics of the village with real existing level coordinates and slopes, which allow analyzing the possible intervention solutions to meet the

Fig. 1 3D point cloud result image in central village area. (Source: Own elaboration)

Fig. 2 Longitudinal section in 3D point cloud in the central area of the village. (Source: Own elaboration)

requirements of accessibility and urban adaptability. Likewise, methods for the classification of the detected building materials [24] can be implemented and the intervention strategies developed below can be implemented in the case study (Fig. 2).

4.1 Case Study

From the analysis of several possible locations, we concluded that it is important to select a location that presents a high degree of depopulation, has existing buildings in disuse, and far from large population centers, but at the same time offers an attractive environment for visitors, with a certain tourist, environmental, and heritage interest. We propose as a case study a rural locality of low population that meets characteristics such as its current depopulation, the need for architectural and structural recovery, as well as the need for social revitalization, located in the south of Spain. The village of "Los Madroñeros" belongs to the municipality of Alájar, located about 2.5 km from it, in the province of Huelva. It is currently in a state of semi-ruin, with a very low permanent population. It is located within the Natural Park of the Sierra de Aracena and Picos de Aroche, offering natural landscapes with fields of chestnut, cork oak, and holm oak forests (Fig. 3).

After the outbreak of the COVID-19 pandemic in our society, it is necessary to rethink current urban planning, its processes, functioning mechanisms, and participation to prevent the emergence and spread of new diseases and to ensure people's safety by facilitating participation in an active life. To this end, it is more necessary than ever to develop open/adaptive approaches to change brought about by the global pandemic and to dialogue with diversified competencies and sensitivities to address the urgent task of dealing more effectively with health and human frailty.

Following these principles, an intervention proposal based on the following strategies is proposed for the case study:

- Urban strategy: Improve infrastructure, access, and treatment of public spaces, connecting them with the surrounding green areas through a network of pedestrian paths that facilitate the interaction of the inhabitant with nature and the municipality of Alájar. To manage the village in a self-sufficient way, promoting

Fig. 3 Views of the village of "Los Madroñeros" (Spain). (Source: Own elaboration)

environmentally efficient measures to improve the facilities in the village: water supply, sanitation (currently non-existent), reuse of rainwater or grey water, renewable energies (photovoltaic panels, solar thermal, geotechnical and wind), intelligent management (home automation, internet and Wi-Fi, currently non-existent). Encouraging the transition to the near-zero energy model.

- Building strategy: Promote the use of materials and techniques deeply rooted in the local building culture of the Sierra de Aracena, and the reuse of the original typology of the existing building, which, on the one hand, ensures the conservation of the heritage and, on the other, the identity of the place's characteristics. This measure also encourages the creation of local jobs and favors the circular economy. Encourage noninvasive technological updating with the environment and support teleworking, digital training, and the social and cultural connection of the village with the rest of the world.
- Component strategy: A component design is proposed based on the double aspect of the enhancement of local materials and craft processes and, on the other hand, with the modularity and ease of disassembly and reuse of the construction system that facilitates its maintenance over time with means available in the environment. Specifically, the use of stone, chestnut, pine and cork oak wood and cork, which are abundant materials typical of this Sierra, will be encouraged. This will facilitate the circularity of the products/components (Refuse, Rethink, Reduce).

5 Conclusion

In this historical moment of extraordinary and accelerated transformations (economic, social, environmental, and health), as well as of growing imbalances and conflicts, in which every single fragility is related to the "whole" and every single action produces an echo or a cascading effect on the users' well-being and the planet health, the debate on the sustainability of development models and rules of coexistence—evidently inadequate to stem and repair the damage caused by past and current crises—is unexpected. The pandemic has highlighted these aspects, but at the same time, it has made us "rediscover" the importance of inner areas (as opposed to areas of concentration) capable of combining innovative housing models characterized by conditions of healthfulness, safety, proximity to natural resources and with innovative models of economic and social development based on the reuse, recycling, regeneration of resources economy (belonging to the rural economy since time immemorial), on the cooperation economy, proximity economy and the "care economy" of a vital and active community. Addressing this issue in the research activity requires the adoption of a systemic approach able to grasp the tangle of relationships among people, territory and built environment, as well as to think about the transformation processes of habitat in relation to human needs. In this area, the synergies between *Environmental Design* and *BIM-based Design* can be an important cognitive source in achieving the possible convergence between:

- *A meta-design vision* that pertains to the definition of requirements, expressible through performance and identified through technological options, making possible the optimization of environmental resources (eco-friendly systems, energy sustainability of buildings, products with low environmental impact in their entire life cycle) and human resources (well-being, participation, social equity, accessibility).
- A *pragmatic vision* of translation and verification of the meta-design with respect to the overall reasons for the territory and the built environment (comparison with the sociocultural, architectural, language, uses, and characteristics that define the identity of a place).

References

1. World Urbanization Prospects The 2009 Revision. (2010). Department of Economic and Social Affairs Population Division. United Nations New York. Available on: https://www.ipcc.ch/apps/njlite/ar5wg2/njlite_download2.php?id=10148
2. CdR, Comitato Europeo delle Regioni. (2021). EU strategy to revitalize rural communities. *Journal of the European Union*. Available on: https://eur-lex.europa.eu/legal-content/IT/TXT/PDF/?uri=CELEX:52020IR1066 & from=EN
3. Smart Villages Revitalising Rural Services. (2018). *EU rural review no 26*. European Network for Rural Development. Available on: https://enrd.ec.europa.eu/sites/default/files/enrd_publications/publi-enrd-rr-26-2018-en.pdf

4. Digital and Social Innovation in Rural Services. (2018). European Network for Rural Development. Available on: https://enrd.ec.europa.eu/sites/default/files/enrd_publications/publi-eafrd-brochure-07-it_2018.pdf
5. Clemente, P. (2018). Paese che vai usanza che trovi, tra cosmo e campanile. *Archivio Antropologico Mediterraneo, 20*(2).
6. Magnaghi, A. (2010). *Il progetto locale. Verso la coscienza di luogo*. Bollati Boringhieri.
7. De Rossi, E., & Mascino, L. (2020). Sull'importanza di spazio e territorio nel progetto delle aree interne. In N. Fenu (Ed.), *Aree interne e Covid* (pp. 48–53). LetteraVentidue Edizioni.
8. Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: Views from urban planning. *American Journal of Preventive Medicine, 23*, 64–73.
9. Imrie, R. (2001). Barriered and bounded places and the spatialities of disability. *Urban Studies, 8*(2), 231–237.
10. King, D. (2008). Neighborhood and individual factors in activity in older adults: Results from the neighborhood and senior health study. *Journal of Aging and Physical Activity, 16*(2), 144.
11. Van den Berg, P., Kemperman, A., de Kleijn, B., & Borgers, A. (2014). Ageing and loneliness: The role of mobility and the built environment. *Travel Behaviour and Society, 5*, 48–55.
12. Forsyth, A., Hearst, M., Oakes, J. M., & Schmitz, K. H. (2008). Design and destinations: Factors influencing walking and total physical activity. *Urban Studies, 45*, 1973–1996.
13. Hooker, S. P., Cirill, L. A., & Geraghty, A. (2009). Evaluation of the walkable neighborhoods for seniors project in Sacramento County. *Health Promotion Practice, 10*(3), 402–410.
14. Brownell, B. (2010). *Transmaterial 3. A Catalog of materials that redefine our physical environment*. Princeton Architectural Press.
15. Tucci, F. (2014). *Involucro, Clima, Energia. Qualità bioclimatica ed efficienza energetica in architettura nel progetto tecnologico ambientale della pelle degli edifici*. Altralinea.
16. Tingley, D., & Davison, B. (2011). Design for deconstruction and material reuse. *Proceedings of the Institution of Civil Engineers – Energy, 164*(p), 195–204.
17. Özkan, T., Pfeifer, N., Styhler-Aydın, G., Hochreiner, G., Herbig, U., & Döring-Williams, M. (2022). Historic timber roof structure reconstruction through automated analysis of point clouds. *Journal of Imaging, 8*(1), 10.
18. Chan, A. P. C., Ma, X., Zhou, W., Yi, X., & Xiong, F. (2018). Critical review of studies on building information modeling (BIM) in project management. *Frontiers of Engineering Management, 5*(3), 394–406.
19. Suwardhi, D., Trisyanti, S. W., Virtriana, R., Syamsu, A. A., & Jannati, S. (2022). Heritage smart city mapping, planning and land administration (Hestya). *International Journal of Geo-Information, 11*, 107.
20. Wang, T., & Xiong, Z. (2021). Methods of As-is BIM reconstruction using point cloud data for existing buildings. *IOP Conference Series: Earth and Environmental Science, 676*(1), 012041.
21. Bolognesi, C., & Garagnani, S. (2018). From a point cloud survey to a mass 3D modelling: Renaissance HBIM in Poggio a Caiano. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives), 42*(2), 117–123.
22. Rodríguez-Moreno, C., Reinoso-Gordo, J. F., Rivas-Lpez, E., Gmez-Blanco, A., Ariza-Lpez, F. J., & Ariza-Lpez, I. (2018). From point cloud to BIM: An integrated workflow for documentation, research and modelling of architectural heritage. *Survey Review, 50*(360), 212–231.
23. Shanoer, M. M., & Abed, F. M. (2017). Evaluate 3D laser point clouds registration for cultural heritage documentation. *Egyptian Journal of Remote Sensing and Space Science, 21*(3). https://doi.org/10.1016/j.ejrs.2017.11.007
24. Hess, M. R., Petrovic, V., & Kuester, F. (2017). Interactive classification of construction materials: Feedback driven framework for annotation and analysis of 3D point clouds. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives), 42*(2W5), 343–347.

Agile-Transdisciplinary Conceptual Framework for Retrofitting Mediterranean Built Environments

Ahmed Abouaiana and Alessandra Battisti

1 Introduction

Transdisciplinarity appeared as a result of the linear development of scientific activity into more new overlapped disciplines [1]. It is identifying the different formulae and the search for unity in produced knowledge that can be joined together, characterized by integrating two conflicting movements of disciplinary thinking. It is essential to reopen scientific approaches to flourish the epistemology to fulfill the same objective, which necessitates constant cooperation throughout the professional practice stages, linking with theories [2–4]. Although the concept has been growing since it emerged in the 1970s, academic progress is still sluggard, particularly in energy research [5, 6] and retrofitting practices as well.

Energy retrofitting practices are essential to achieve numerous benefits for the environment and humans that almost interact with all sustainable development goals [7]. However, they are highly complex processes [8]. That is epitomized in the accompanying obstacles, which can be related to legalizations, policies, socio-culture, and techno-economic factors, from one side [9–12] and managing the relationship between the stakeholders themselves [13–15]. Especially in rural Mediterranean commons that are characterized by locals' enclosed nature and distinguished landscape-cultural values, besides facing exclusive environmental challenges as one of the most fragile and sensitive areas due to climate change exceeding the global averages [16, 17].

Thus, from the fact of the complex and interlocking relations among the collaborators in traditional settlement retrofitting practices, we focus on stakeholders

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themselves as we believe engaging and managing the right, and not the available, stakeholders is a real challenge. That can ensure the process's success and solve the interconnected real-world problems, as has been emphasized in the Refs. [18–21].

The initial step of project communication management is to identify the people and organizations (stakeholder identification) who possibly impact (positively or negatively) and are interested in the project. Then to be classified (stakeholder classification) based on similar interests, and claims, to their roles and attributes. That can be grouped into three domains. Firstly, the high-engaged stakeholders (internal, primary, or participating) provide a highly active contribution that impacts the objective. Secondly, the low-engage stakeholders (external, secondary, non-participating) indirectly affect the decisions, like the interviewed locals to explore their perception about a given issue. Thirdly, supportive stakeholders (sponsors or intermediaries) who facilitate the process, like NGOs [22–24].

Although the proven role of stakeholders' engagement, the conflict between them is inevitable and remains a significant barrier [25], also in organizations, groups [26], and any project environment [27]. Transdisciplinarity itself is characterized by conflict [28]. Many previous studies publicized several aspects that affect conflict in collaboration. For epitome, include poor communications [29], cultural diversity [30], and lack of coordination [31]. To clarify, those related to different languages understand the local culture and proper name pronunciation. In addition to feedback to team members, such as avoiding questions on the received feedback, even the wrong, because, in some cultures, it may mean disrespect.

Thus, this research aims to provide a novel transdisciplinary framework that integrates energy retrofitting and project management practice with the agile methodology initiated in software development, which proved a successful and efficient team management tool in software and other domains. Likewise, we hypothesize that the agile framework will succeed in resolving the anticipated problems between the selected stakeholder and organizing their relations, in addition, to mitigating the uncertainties associated with retrofitting process in traditional Mediterranean settlements and as a sequence will succeed in implementing the retrofitting.

2 Materials and Methods

2.1 Methodology and Limitations

The study integrates different methods in order to achieve the aims. Firstly, theoretical and analytical methods: are based on the relevant theoretical concepts about the three domains (software engineering and project management with energy retrofitting practices). To answer three questions: To what extent can the agile methodology be adopted in transdisciplinary practices? What are the restrictions and benefits of adjusting the agile method in collaborative work? Finally, what is the agreement level about the participatory approach?

Secondly, field study and qualitative methods: applying the proposed framework to two similar traditional settlements in developing and developed Mediterranean countries, representing the entire region, respectively, Lasaifar Albalad village, Egypt, and Pontinia village, Italy, and then validating the proposed framework using the focus group technique. Notably, this study is integrated with the findings of a previous publication provided recently by the authors [32]. The study is limited to the planning and early decision-making and planning stages in Lasaifar Albalad and Pontinia, followed by an on-ground implementation conducted only in Lasaifar Albalad.

2.2 Agile Methodology—Introduction

Agile terminology means "moving quickly" [33]. It is a justified, engineering-based approach [34], characterized by the ability to create and react to change implied by a massive collaboration where the team works together comprehensively toward a shared aim [35]. The "Agile Alliance" developers originated the concept in 2001 within the "Manifesto for Agile Software Development." The manifesto comprises four pillars: people, communications, deliverables, and flexibility. Namely, paying consideration to efficient management of the relations among the engaged stakeholders, delivering products with the highest priority and maximum value, achieving client satisfaction, and continuous adaptation regarding inputs variations and fluctuations [36, 37].

"*When the water falls, it cannot go back up*" [38]. Hence, the *waterfall* methodology (the traditional approach) employs a consequent or linear method for software development [39]. That tolerates high costs and risks that affect information management efficiency. The customers are excluded [40] or participate in beginning and following up until receiving the completed deliverables to be seen succeed or not. It is a documentation-driven and heavyweight process [41]. In project management, the waterfall process is a linear and straightforward process. Simply, when the step finishes, the next starts. The requirements and data are being collected and documented from the beginning, including the expected outcomes.

Vice versa is that the agile approach is divided into short phases based on iterations and multiple deliveries. The team is multidisciplinary. The customer is involved as an active contributor. Changes in deliverables are anticipated and less impactful. It is a more collaborative and transparent approach [42]. It counterpoises the unstable requirements during all product life cycle phases in a short time and within the budget [43].

In managing retrofitting projects, for instance, the traditional approaches within the construction industry are weak because of a lack of client interest, monitoring, and limiting testing to check performance. Otherwise, the project retrofitting coordinator (rather than a project manager) is essential to support the stakeholders and improves the process [44]. Fox [45] mentioned retrofitting project management within firms requires more consideration than any domain because the process faces additional risks, like overtime and unforeseen events. Thus, the team members and project managers should interact efficiently and have sufficient experience and interest, and they should clearly define objectives and roles to be aligned with the project.

2.3 Agile Methodology in Project Management and Software Development

Agile methods are a set of practices in software development, including many frameworks, such as eXtreme Programming [46], Lean [47], and Scrum [48]. All focus on social factors as a mainstream practice in the field [49]. The basic principle is to amplify the business value, reduce product development tasks, eliminate needless things that affect the completion, and get rapid feedback. Meanwhile, it can make flexible decisions in the late stage of the project. To solve problems with long-term solutions, not just symptoms [50].

In general, creating an agile environment requires three elements. Firstly preparing mindset: determines how the project member can act in an agile and transparent manner, what they can deliver rapidly to get feedback, and how they can act? Second, leaders (facilitators) play a crucial role in team empowerment, accomplishing the goal, and removing organizational obstacles. Thirdly, aspects related to team structure.

While delivering an Agile project (implementation) requires four phases. First, the project charter is essential to describe how the team works together regarding the shared vision. Second, the standard practices enable learning from the past to enhance the current by refining the backlog. Third, challenges troubleshooting, such as unclear aims and needs. Fourth, quantitative and qualitative measurements facilitate the agile transition.

In a nutshell, as it is evident, we can describe the agile mindset as continuous development and a resilient methodology. In the meantime, we believe the traditional way is not wrong. It is a matter of limitations, context, political situation, and the whole scene, supporting Ref. [51] findings. However, we argue that the agile mindset fits our argument (providing efficient micro-transdisciplinary practices). We selected the Scrum tool for two reasons: the annual survey among practitioners from 100 countries demonstrated that it is the most common approach, and 81% of the respondents use Scrum models [52]. Also, it proved effective in different domains, like the construction industry [53], non-software production industries [54], and education [55].

3 How Does Scrum Model Work? [56, 57]

Scrum is like "*the rugby huddle, and the players come together to possess the ball*" [58]. Regarding the Scrum Glossary—it helps "*people, teams, and organizations to convert ideas to values through adaptive solutions for complex problems*" [59]. Sprint is Scrum's core. Regarding the Scrum Guide [60]: Scrum determines the stakeholders' roles (framework) rather than guiding how to accomplish the tasks (methodology). The project life cycle is divided into small and repeated segments (one or more sprints) until the product (service) is completed. Where each member implements different artifacts within a particular event, each sprint is implemented with a length of 1 month or less to create coherence. Therefore, Scrum is an interlocking matrix grouped into three pillars: stakeholders, artifacts, and events (ceremonies), Table 1. The components of the Scrum framework.

The first pillar is the team (involved stakeholders) that should consist of (3–9) members. The projects can also consist of many scrum teams regarding the nature, goal scale, and requirements. It is evident that the smaller the team members, the higher the communication and productivity. Firstly, the *PO* is responsible for setting the agile environment, namely, stating the vision from a top-down, creating the roadmap, total responsibility of the product log set, and the aims of the iterations *Sprints*. The *PO* is a concept or process rather than a person.

Secondly, the *SM* is the *servant-leader* responsible for handling the environment and team jointly and defining the characteristics of the requirements, either products or an outcome in any topic such as energy retrofits, to facilitate the entire process. The *SM* could be an external expert (e.g., a university professor or regulations expert) who enhances the performance and communications of the team. Thirdly, the *DT* is a talented member, is self-organized should have multidisciplinary skills responsible for receiving the main goal from the *PO*, developing the project, creating the micro plans for the *Sprint*, and ordering and testing the *Sprint Backlog*.

The members ensure the effectiveness, integrate the outcome with the whole system, and create the necessary documentation, and the output is defined as (*Done-Work*) approved in *Sprint Backlog*. Once the output in the *Sprint* is a "marketable feature," it is called *Release* to receive end-user feedback. By projecting the Scrum practices to the study context (retrofitting), the involved stakeholders help attain the project goal. Theoretically, Scrum promotes cross-functionality and multidisciplinarity skills among the team. We developed this to transdisciplinarity because of the engagement of the locals, academic and non-academic.

Table 1 The featured components of the Scrum Model

Scrum Pillars	Description
Team (Stakeholders)	Product (Scrum) Owner (PO), Scrum Master (SM), and the Development Team (DT)
Artifacts	Product Backlog, Sprint Backlog, and Increment
Events (Ceremonies)	Sprint, Sprint Planning, Daily Scrum, Sprint Review, Sprint Retrospective

The second pillar is the *Artifact* of the project documents. The *Product Backlog (PB)* is the only source for tasks that the teamwork should respect. It is an emergent, ordered list of what is needed to improve the product to determine how the *Product Goal* will be achieved. It is the only source for issues that the team should respect. The stakeholders' requirements (needs) are classified under midsize items (epics) and themes.

For example, each story should state: *As a Stakeholder (role), I want (a goal), so that (benefit)*. The aim is to enable the *PO* to refine the project details' boundaries (e.g., required time). The *Acceptance Criteria* (common scenario-oriented approach) should accept the *User Stories* that describe the criteria in the *Given/When/Then* format to look at the problem (or risk) from the end-user perspective [61]. What was implemented in Lasaifar Albalad can be taken as an example; the Given was (the first author had to inform the local authority) When (he met the stakeholders in the village) Then (he should engage an employee from a public body).

The target outcomes are the scope clarity, acceptance of all requirements, accepting all necessary risks and mitigating them, and sizing the requirements within the *Sprints*—this so-called *Product Backlog Refinement*. This process consumes 10% of the total sprint length (1–4 weeks). It frequents as needed. It enables the team better understands the items and prepares them for further Sprints.

The next stage is *Release Planning*. It is a high-level timeframe for realizing a group of product requirements, from the highest priority to the lowest features, offering a pivotal place for the project team to assemble. Based on the goal, the number of *Sprints* can be determined. Each release plan has a release goal (if any requirement is not associated with the goal is kept in the *PB* until it supports another goal). All goals should be prioritized. Why is this requirement necessary? Which requirement has the high risk to be tackled first? Finally, what is the minimum set of (the must-have) features to achieve customer values and quality expectations?

The third pillar is the *Events (Ceremonies),* where the life cycle consists of five events, as discussed, the *Sprint* and *Sprint Planning* (e.g., Sprint goal, vision statement). Then the team starts the implementation phase, which coordinates the tasks in the *Daily Scrum*. Next, the *Sprint Review* to justify the working product (by *Sprint's* end) to be complete for delivery or to collect feedback on what the team has finished and inspect the overall roadmap PB. It is about the product meeting the user's needs. The *Sprint Review* meeting should include all the stakeholders. Finally, the *Sprint Retrospective* (Sprint conclusion) is provided to the internal stakeholder (the team) to evaluate the work by the end of each sprint. Thus, it is an action-oriented approach to improving team skills. Figure 1 summarizes the Scrum framework.

As a result, this study developed Scrum Zero, and the implemented literature review using (Scrum and Retrofitting) keywords proved that no reference indicated this issue before. Specifically in energy retrofitting practices[1] in rural Mediterranean

[1] Noteworthy, the only implementation of the Scrum into retrofitting was within a project in 2015 in the Netherlands, to retrofit a small building, as discussed in Ref. [70]. The similarity with our study is the limited team members and the building scale. Contrariwise, they belong to the same organi-

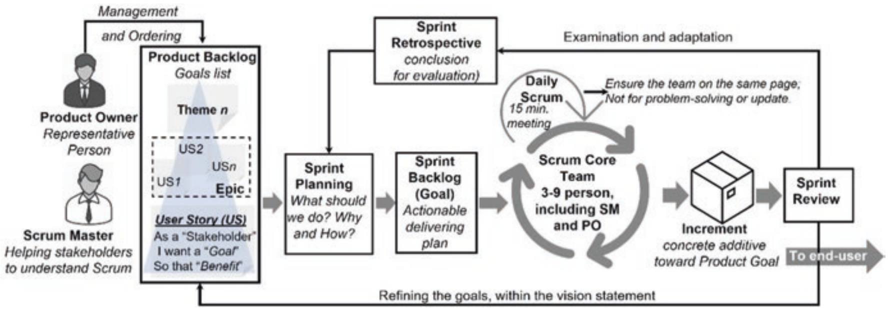

Fig. 1 A summary of the process of the developed Scrum framework. The study developed a novel definition of the proposed team: including academics, local authorities, and locals (the scrum team usually consists of technical experts). The "Product" is redefined as the required intervention in the villages of Lasaifar Albalad and Pontinia

commons. As a supportive step, the first author has contacted an expert software engineer[2] to discuss the related Scrum issues to enhance framework validation. In this case, in line with the adaptive nature of Scrum, the estimation should be fine-tuned based on our experience (waterfall approach), supporting what we have argued: "the traditional way cannot be excluded totally; however, we promote an agile approach."

In sum, Scrum utilizes an incremental and iterative way to mitigate the uncertainty (risks prediction) and engages members with sufficient skills to carry out work. Scrum model is an empirical-based approach characterized by transparency**.** All project limits should be visible to the team to ensure that the project aligns with the work procedure's goals (inspection to explore any emerging problems for adapting to the obstacles instantly and correcting the compass). This agile life cycle occurs through a dynamic environment based on repeat-until-correct and partial deliverable tasks to receive participatory feedback (from the stakeholders) and achieve the end-user value (local community, supporting the national policies, and the academic enthusiasm).

zation and have the fund to implement the intervention (which is absolutely different from our study). We also observed the project's timetable shown in Ref. [71]. The sequence of the time frame was going linearly (traditional way), and it is not clear enough how the discussion with the team back looped into planning (the agile iterative nature).

[2] The first author acknowledges the technical support (four online discussion sessions) from engineer Mohamed ElSerngawy https://ca.linkedin.com/in/mohamed-elserngawy-46637510 (Accessed 27-06-2022) about the scrum practices in the software domain.

4 Framework Validation and Sprint Zero in Both Contexts

The participatory approaches are crucial for energy transition [62], with community participation, especially in rural development projects [63]. By considering their generic obstacles, such as socio-cultural ones, in other words, how to enhance local belonging to possessing development, and legislative and administrative obstacles like bureaucratic laws and the conventional one-way communication (top-down) [64], which is proved its failure (without bottom-up) [65]. We implemented broad discussions with the locals in both contexts to consider the barriers. After a deep on-site investigation and face-to-face discussions, it was easy to identify the influencers in both contexts, highlighting the critical role of contacting the locals on the ground (as one of the transdisciplinary characteristics). The details of the framework validation were concluded in Ref. [32].

In Sprint Zero, briefly, the vision statement is to decide together and be on the same page to retrofit our built environment within the potential and the obstacles. Simultaneously, the first author acts as SM (servant leader) responsible for explaining the technicalities of the scrum principles. DT was the selected stakeholders, including versatile participants[3] (decision-makers, locals, cultural experts, and local suppliers). The entire process was mentored and supervised by the second author. The initial Sprint Planning was estimated at 1 week and making a plan to reach the goal the development team aims to fulfill within the Sprint.

We found that Scrum helps determine an effective work procedure that combines short iterative development and assessments, leading to holistic reviews and in-depth feedback. The initial Sprint in the retrofitting process is the validation process- Sprint Zero. In Pontinia, the intervention started from a bottom-up approach and ended with support from the Municipality. The authors acted as PO and SM (client), who stated the requirements, vision statement, and goals (aimed to assess the participatory transdisciplinary framework). Then, the sprint review process with the stakeholders from different perspectives. Table 2 localizes the developed scrum practices within our intervention.

It is noteworthy that the Ref. [66] has argued that Italy is an unusual country in Europe in every aspect, including project management, characterized by continuous changes in planning, as supported by the Ref. [67]. That gives a rudimental indicator to understand the local Italian culture. Consequently, we advocated that understanding the local culture (daily life situations, traditional music, and movies) enhances communication and project performance. Supported by the Latin statement "*Si fueris Romae, Romano vivito more.*[4]" Thus, the first author (as a foreigner) gave heed to these details 3 months before the on-site investigation. He noticed the argument's effectiveness, represented in the high appreciation from the locals while implementing the practical part and their willingness to do something for their community.

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[3] The significant variance between the software development and the Netherlands practice are the limited team to the technical ones.

[4] Latin statement attributed to Saint Ambrose, it means: *If you are in Rome, live according to the Roman custom.*

Table 2 Localizing the scrum practices within the workshop, integrated with Ref. [32]

Team	Artifact	Event	Description
PO & SM	Product Backlog	Vision statement	Stating the vision (developing a built environment together, e.g., energy communities). The necessary work to fulfill the project objective orders these needs into a list. PO shows a requirement to the members, asks questions, and mange discussion.
PO,SM& DT	Sprint Backlog	Sprint Planning (Direct goals)	*What can be accomplished and delivered as Increment* (How can we do it). What are the obstacles and benefits (approving the user stories). Localizing the concept of agile and scrum. What are their point of view directly about both framework and suggested interventions. How can we implement a real scenario case?
PO	Sprint Backlog	Sprint Planning (indirect)	Observe their facial expressions, communication levels, and preferences.
PO and Sponsors	Sprint Backlog	Daily Meetings	Preparing for the workshop activities (Short meetings with facilitator stakeholders) and inviting the stakeholders.
PO and External	Supportive item	Daily Meetings	Preparing for the workshop technically and short face-to-face with volunteer external experts (researchers) and the mentor to receive feedback about the framework.
DT	Increment	Sprint	The sum of all the elements that were accomplished during the Sprint.
PO,SM& DT	Increment	Sprint Review	A summary of the accomplished tasks. Estimating the delivery dates and those targeted for the next Sprint.

4.1 Framework Refinement—Further Sprints in Lasaifar Albalad

Refining the framework has been conducted in the Egyptian case study only. Based on the outcomes of the initial Sprint, the framework has been adjusted at many levels, namely, the financial aspects, finding a pilot case study and a local representative, time frame, risks, and clear scope. We promoted solar energy for the self-consumption purpose (the initial step of the energy community). Which was accepted as one of the optimum accepted user stories (Sprint Zero) in terms of micro-scale, solar availability, technicalities know-how, and short implementation period, considering resolving the associated uncertainties, which can be grouped as shown in Table 3.

For elaboration in Sprint One, it took 2 weeks to plan the project, starting with the one-to-one meetings (online and by telephone) between the stakeholders. The meeting discussed the client's needs, which had two concerns. First, to what extent the supposed system is safe for the building structure (the technical investigation confirmed, yes). Second, what is the possibility of removing and reinstalling the cells in case of any future extension? Therefore, we conducted a flexible structure.

Then the SM and DT of Edara implemented technical meetings (two daily scrums) within a week to discuss potential solutions (self-consumption, on-grid, or off-grid). After every meeting, the SM contacted the client online to simplify the conclusion. No feedback was received, only clarifications and answered immediately. The technical tasks have been divided between the SM (spatial and architectural analysis) and Edara's DT (solar energy technicalities). Two days later, a daily scrum was implemented (by phone) between the SM and DT leader, followed instantly by a call with the PO. No feedback was received.

The technical and financial file was received on 23 January 2022.[5] The SM immediately discussed it with the client and approved it in 2 days. Then, Sprint two was started to install the photovoltaic. It was planned to implement in 10 days due to the capability of the donor, considering that they are usually working in Cairo and they have their working procedure. The aim was to implement a pilot project in the village relying on renewable energy and avoiding retrofitting the buildings. Table 4 summarizes Sprint One's tasks.

Table 3 The outputs of the Sprint Zero (inputs to Sprint One)

Sprint One Inputs	Description
Input 1: Specific intervention	The vision statement, self-consumption buildings (zero energy building) serving the local community.
Input 2: Target case	The proposed building should be one of the public buildings, the health unit (which has been excluded), or one of the social buildings, the NGO private building. The aim is to implement the first (rapid) pilot study in the settlement (including the satellite villages).
Input 3: Socio-culture barrier	Convincing the client to accept the intervention (although their enthusiasm, it took 2 days to accept).
Input 4: Economic barrier	The author convinced a communities development company, "Edara" [68] (a representative was involved in the focus group), to support a pilot project as a societal role due to their internal policy.
Input 5: Setting the project and communication plan	The team consists of the PO: NGO (the client), SM: the first and second authors (coordinator and mentor, respectively), and DT, Edara Company (financial and technical support).

[5]The file is attached to the Project Log, available at: https://www.researchgate.net/project/Retrofitting-Built-Environment-in-Traditional-Settlements-in-Mediterranean-region-towards-Energy-Communities-Egypt [In Arabic] (Accessed 27-06-2022).

Table 4 Sprint One’s summary

Item	Description
Tasks	Receiving the client’s feedback, preparing detailed technical analysis, and approving the financial support, in line with the vision statement and including user stories in the product backlog (resulting from Sprint Zero).
Increment	Providing the technical offer, approving the funding, and preparing the user stories for the upcoming Sprint.
Scope Refinement	Selecting the proper technical solution after discussion.
Duration	Two weeks.

Table 5 Sprint One’s summary

Item	Description
Tasks	Implementing the first self-consumption building, using an off-grid solar plant (3 kW), in line with the vision statement and the included user stories in the product backlog (resulting from Sprint One)
Increment	First self-consumption building from 100% renewable energy
Duration	Six days

4.2 Sprint Two

Sprint two took 6 days to prepare for the implementation phase. In this step, the tasks are divided into the team, the architectural analysis and communication provided by the SM, and solar panel technicalities provided by the DT (Edara’s technical team). The approved funding was 48,000 Egyptian Pounds (EGP) (equaled to 2693 EURO in January 2022) to install the solar plant. The target building is located in Lasaifar Albalad, between coordinates 31°10′55.9″N 30°43′06.1″E. It is a typical one-story residential building with a different function: “Albakyat Alsalihat” NGO. The building provides many social services: a nursery (serving around 75 kids between 3 and 5 years) and orphan care. The area is 150 m^2, and the ground floor consists of one main hall, five classrooms, two toilets, a lobby including a kitchenette, an external store, and a stair leading to the roof.

In the second step: the data on the electrical appliances and electricity bills were collected. Building operation and occupant energy consumption behavior were discussed with the client. The maximum operation hours are between 7:00 am and 7:00 pm. The night load is for the fridge only. The total load is estimated at 6502 Watt/day. The load capacity (instantaneous total) is 2438 watts/day. So the inverter equals 2925 watts/day (3 kW) approximately. The peak charge plant was designed as per location peak sun hours 5 hours/daily to charge the batteries and feed the mentioned load for 24 hours. Table 5 summarizes Sprint Two’s tasks.

The implementation day was determined as 29 January 2022. Then, three associated risks to Sprint Two emerged: First, although the date was chosen after checking the weather forecast to find a sunny day (this time of year is rainy). Some local internal road networks (narrow two-way) suffer from heavy mud between some

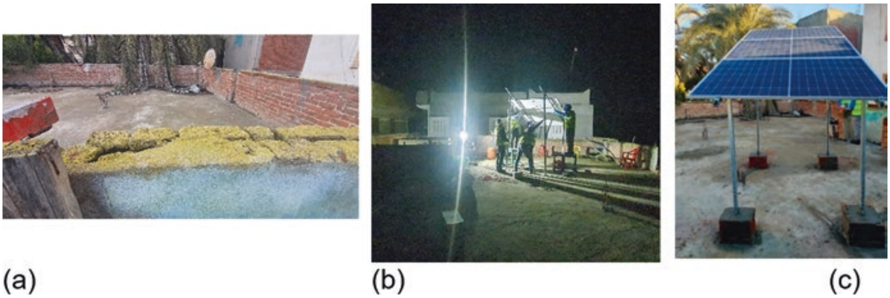

Fig. 2 The target building's roof (taken by Ahmed Abouaiana). (**a**) Green molds fungus indicates that the client ignores the roof and maintenance behavior post-retrofitting; (**b**) demonstrates work progress during the night; (**c**) shows the solar plant after completion

districts and rural settlements (due to heavy rains in the past days), limiting car speeds. Consequently, the equipment vehicle arrived 3 hours later, near sunset time. Hence, the installation was implemented at night to avoid consuming more time and money if the work was postponed to another day.

Another observation was the unoccupied roof beside the green molds on the brick parapet of the roof, Fig. 2a, which reflected that the client neglected the roof. The anticipated risk was the lack of maintenance by the client post installing the plant. Consequently, the team has stressed weekly operation and maintenance instruction and provided technical training. Finally, when the client stated, "*what if the system dropped? How can we retrieve the conventional electricity source?*" For this reason, although Edara guarantees this off-grid system technically, the plan was modified immediately (agile way), and a switch was added (2 days later) instead of the direct connection from the solar plant to the internal electrical distribution panel to enable switching.

4.3 A Nascent Practice and Promising Outcomes

The experiment is accomplished, and now the first self-consumption building in the village consumes the total produced energy from January until writing this paragraph (July 2022). We declare that the experiment is still in a too-early stage, but encouraging preliminary results have been achieved in the first week. First, socially, a wide segment of the inhabitants expressed their interest (on the Facebook platform, by phone, and through direct contact with the client) to know more details, asking for visits to see this "new" technology, and asked for its feasibility. A local said, "*really can I avoid paying 250 EGP of the monthly electricity bills?*". The kids expressed happiness in asking to see the experiment and about capturing photos wearing the safety helmets. The client herself expressed her gratitude for the "new" experiment.

Fig. 3 The author was interviewed on the official national TV program [69]. This may reflect the social impact of the experiment

Secondly, in raising awareness realm. In discussion with the client. Two additional findings were provided, to include simple environmental aspects (e.g., this experiment) in the teaching activities in the nursery (teaching now is limited to religious subjects and reading skills), considering that no structured curriculum developed. In addition to suggesting a public playground, serving the village's kids was suggested in front of the nursery. The project is planned to implement soon by the NGO.

Thirdly from the media side, after 2 days of publishing the experiment on social media platforms, the first author was invited to an interview in the official national program "Good Morning Egypt" to discuss the project results, Fig. 3. This interest reflects two crucial aspects: the importance of bottom-up practices and the role of the researchers and architects in developing the built environment, and the government's support for these kinds of interventions in line with (Goal 4, supporting innovation and scientific research) Egypt Vision 2030 to achieve sustainable development goals. In addition to the extraordinary attention, to all green initiatives, in line with hosting the UN Climate Change Conference (COP27) as planned in November 2022.

5 Conclusion

Built environment energy retrofitting is crucial to promote sustainable development objectives, mitigate climate change, and improve quality of life. The academic community pays great attention to energy efficiency, represented in the significant increase in the academic publications related energy efficiency domain in the last 20 years. Jointly, the nature of the retrofitting practices is too complex due to internal or external factors, unlike any domain. What requires an intensive focus from various stances to mitigate these uncertainties. For this reason, integrating the efforts of academic bodies (as knowledge brokers) and practitioners across the different disciplines besides the local community, in other words, the transdisciplinarity can contribute efficiently to solving real-world related-energy problems, particularly in distinguished environments with limitations and characteristics like the traditional Mediterranean settlements.

That influences the global environmental scene (top of the pyramid), such as climate change, and the individuals (base of the pyramid), like paying much in energy bills. Although the vast benefits of transdisciplinarity, it is ambitious because it conceptualizes how to work, not what to do in detail for a specific project, and how to manage the interlocking relationship between the collaborators. This Study proposed a transdisciplinary approach by following systematic procedures to rationalize this ambition.

In the study context, the agile scrum method paved the way to resolve the expected conflict between team members. It deals with the high-level obstacles, namely, the interest of the decision-maker and locals with the research objective, requiring to clear the vision and mitigating the associated uncertainty, guiding the project's "servant leader" (the lead researcher) on how to educate, and monitor the team, and evaluate the process.

5.1 Conceptual Framework Novelty

In theory, this research is the first to provide integration of an agile mindset in retrofitting rural built environments in the Mediterranean region. By elucidating the interconnectedness with the nature of the energy retrofitting practices, where conceptualizing the uncertainty linked with it can be reduced. This occurred via a review of the relevant notional concepts about the trends related to cross-disciplinarity energy retrofitting practices. That is associated with the agile methodology practices of project management and software development domains, resulting in a framework that helped organize collaboration, enhance communication, and support planning and decision-making to retrofit. As a result, the study achieved triple contributions that positively impact the local society and the scientific community, and support the national policies.

The first category is energy retrofitting. The study localized the takes global challenges at a micro-scale by investigating the practices advocating more coordination between actors from a transdisciplinary perspective, manifests the acquaintances among the ability to involve the local community, decision-makers, academic bodies, and experts. Which is essential to enhance the energy efficiency, mitigate climate change and valorize the local identity with resilient strategies.

The second category is the project management domain. Improve the skills of the team members to understand the nature of projects, life cycle, management approaches, and how to ensure project success (team, work environment, and process). Furthermore, understanding the local socio-cultural aspects underlined a new approach to identifying the stakeholders. The third is software development. The scrum model provided practical steps to develop software products. Thanks to the rapid acclimatizing way that enabled us to eradicate superfluous things providing adaptable choices, effacing the given issue along the life cycle, and establishing broad lines between the team to improve their relationship.

The framework empowers information exchange, which in this study refers to a new way of interacting cooperative working, including simplifying the transdisciplinarity, involving all relevant stakeholders in the project development process, resulting in better collaboration and communication, and decision-making.

The scrum framework empowers information exchange, including simplifying the transdisciplinarity. This study refers to a new way of interacting in cooperative working. It promotes a better understanding of implementing efficient retrofitting strategies that provide a rapid adjustment of the work plan and equal feedback from the engaged stakeholders. That proved a success in mitigating the uncertainty in energy retrofitting practices. In addition, the short iterations helped adjust the project path at any time, only under a mainstream aim and precise inputs. It also helped in engaging the stakeholders and increasing their expectations. In addition, it upgraded the bottom-up way to a mixed one (with the top-down), as proved in Lasaifar Albalad and Pontinia.

Although the study focused on Egypt and Italy as representatives of the entire region, investigating different Mediterranean countries may lead to different results. The study was limited to the traditional farming-based settlements and the plain areas (morphologically). The research implementations did not apply to the historical and cultural heritage settlements. The real case scenario has been implemented in Lasaifar, while in Pontinia, it was limited to the planning phase.

From a local cultural perspective, we argue it will be a tendency among the other inhabitants. The novelty is the provided Scrum framework and all its connected procedures that enabled deducing sufficient feedback and preferences from versatile stakeholders and juxtaposing them on the same page using a restricted methodological approach. Besides, juxtapositioning versatile stakeholders on the same page using a restricted methodological procedure.

Meanwhile, we found that the researchers' social and cultural skills and life experience go hand in hand with technical skills. In addition, studying the historical background of the place, music, architecture, and local language can facilitate any on-site intervention. Thanks to social media platforms and ICT that helped in this, they played a significant role in communications in the exploratory phase. Especially as the first author, a foreign researcher working in the Italian context, observed a positive reaction from the Italians toward this, regardless of the techno-economic obstacles.

Scrum proved a successful tool for implementing the project, represented the rapid communications among the stakeholders, adjusted the work plan due to different inputs, enhanced the collaboration among the collaborators, and finally, no conflict was detected. The conversations with stakeholders and citizens are vital for creating groundwork. It is inevitable to implement a field study after the theoretical preparation. It affected the process positively.

To conclude, this paper has proposed a new direction of the investigation, which moves from a conceptual framework toward an agile practice to provide a new participatory approach that empowers knowledge exchanging and developing a cognitive model that can simplify transdisciplinarity interactions, involving all relevant stakeholders, enhancing the communications that enable possible retrofitting solutions of the Mediterranean built environment, on the one hand, and the other, showing how could it improve the capacity of researchers and practitioners, who promote bottom-up rural development interventions.

Finally, although the promising future of the intervention, we declare there is an essential need to evaluate the whole experience post-implementation and monitor it. Each part has its challenges, obstacles, and known and uncertain risks. Likewise, the scrum filled a gap in the early stage it might succeed in the further steps.

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Informed Consent Statement Informed consent was obtained by the first author from all subjects involved in the study.

Data Availability Statement Some data that support the findings of this study are available from the first author upon reasonable request.

Conflicts of Interest The authors declare no conflict of interest.

References

1. Ramadier, T. (2004). Transdisciplinarity and its challenges: The case of urban studies. *Futures, 36*, 423–439. https://doi.org/10.1016/j.futures.2003.10.009
2. OECD. (2020). Addressing societal challenges using transdisciplinary research. *OECD Science, Technology and Industry Policy Papers*. https://doi.org/10.1787/0ca0ca45-en
3. Evely, A. C., Fazey, I., Lambin, X., et al. (2010). Defining and evaluating the impact of cross-disciplinary conservation research. *Environmental Conservation, 37*, 442–450.
4. Lawrence, R. J., & Després, C. (2004). Futures of transdisciplinarity. *Futures, 36*, 397–405. https://doi.org/10.1016/j.futures.2003.10.005
5. Schmidt, S., & Weigt, H. (2015). Interdisciplinary energy research and energy consumption: What, why, and how? *Energy Research and Social Science, 10*, 206–219.

6. Cohen, J. J., Azarova, V., Klöckner, C. A., et al. (2021). Tackling the challenge of interdisciplinary energy research: A research toolkit. *Energy Research and Social Science, 74*, 101966.
7. Shaikh, P. H., Shaikh, F., Sahito, A. A., et al. (2017). Chapter 9 – An overview of the challenges for cost-effective and energy-efficient retrofits of the existing building stock. In F. Pacheco-Torgal, C.-G. Granqvist, B. P. Jelle, et al. (Eds.), *Cost-effective energy efficient building retrofitting* (pp. 257–278). Woodhead Publishing.
8. Okorafor, C., Chetty, R., & Haupt, T. (2021). A framework for implementing energy retrofit projects in existing building in South Africa. *IOP Conference Series: Materials Science and Engineering. IOP Publishing, 1107*, 12001.
9. Butt, B., Jones, R. V., & Fuertes, A. (2021). Opportunities and barriers to business engagement in the UK domestic retrofit sector: An industry perspective. *Building Services Engineering Research and Technology, 42*, 293–305.
10. Jia, L., Qian, Q. K., Meijer, F., & Visscher, H. (2021). Exploring key risks of energy retrofit of residential buildings in China with transaction cost considerations. *Journal of Cleaner Production, 293*, 126099.
11. Abouaiana, A., & Mendonça, P. (2022). Retrofitting dwellings in traditional coastal settlements in Egypt and Portugal using nature-based solutions and conventional thermal insulation materials: Technical and economic assessment. *Journal of Architectural Engineering, 28*, 05022005. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000537
12. Abouaiana, A. (2021). Retrofitting rural dwellings in delta region to enhance climate change mitigation in Egypt. *Environmental and Climate Technologies, 25*, 136–150. https://doi.org/10.2478/rtuect-2021-0009
13. Sibilla, M., & Kurul, E. (2020). Transdisciplinarity in energy retrofit. A conceptual framework. *Journal of Cleaner Production, 250*, 119461.
14. Jia, L., Qian, Q. K., Meijer, F., & Visscher, H. (2020). Stakeholders' risk perception: A perspective for proactive risk management in residential building energy retrofits in China. *Sustainability, 12*, 2832.
15. Ongpeng, J. M. C., Rabe, B. I. B., Razon, L. F., et al. (2022). A multi-criterion decision analysis framework for sustainable energy retrofit in buildings. *Energy, 239*, 122315. https://doi.org/10.1016/j.energy.2021.122315
16. Cramer, W., Guiot, J., & Marini, K. (2018). Risks associated to climate and environmental changes in the Mediterranean region. MedECC Report. p. 35.
17. Lange, M. A. (2020). Climate change in the Mediterranean: Environmental impacts and extreme events. In IEMed (Ed.), *IEMed: Mediterranean yearbook* (pp. 30–45). European Institute of the Mediterranean.
18. Zedan, S., & Miller, W. (2018). Quantifying stakeholders' influence on energy efficiency of housing: Development and application of a four-step methodology. *Construction Management and Economics, 36*, 375–393.
19. Bryson, J. M. (2004). What to do when stakeholders matter: Stakeholder identification and analysis techniques. *Public Management Review, 6*, 21–53.
20. Nguyen, T. S., Mohamed, S., & Panuwatwanich, K. (2018). Stakeholder management in complex project: Review of contemporary literature. *Journal of Engineering, Project, and Production Management, 8*, 75.
21. Li, Y., Li, M., Sang, P., et al. (2022). Stakeholder studies of green buildings: A literature review. *Journal of Building Engineering, 54*, 104667.
22. Fasna, M. F. F., & Gunatilake, S. (2020). Involvement of stakeholders in the adoption and implementation of energy retrofits in hotel buildings. *International Journal of Energy Sector Management, 14*, 1239.
23. Stellingwerf, R., & Zandhuis, A. (2013). *ISO 21500 guidance on project management–A pocket guide*. Van Haren.
24. Smith, L. (2000). *Stakeholder analysis: A pivotal practice of successful projects*. Project Management Institute Annual Seminars & Symposium.
25. Rahim, M. A. (2017). *Managing conflict in organizations* (4th ed.). Routledge.

26. Jehn, K. A. (1994). Enhancing effectiveness: An investigation of advantages and disadvantages of value-based intragroup conflict. *International Journal of Conflict Management, 5*, 223–238. https://doi.org/10.1108/eb022744
27. PMI. (2017). *A guide to the project management body of knowledge (PMBOK guide)/Project Management Institute* (6th ed.). Project Management Institute.
28. Klein, J. T. (2008). Evaluation of interdisciplinary and transdisciplinary research: A literature review. *American Journal of Preventive Medicine, 35*, S116–S123.
29. Chan, L. H., & Chen, C. (2010). Conflict from teamwork in project-based collaborative learning. *Performance Improvement, 49*, 23–28.
30. Millhous, L. M. (1999). The experience of culture in multicultural groups: Case studies of Russian-American collaboration in business. *Small Group Research, 30*, 280–308. https://doi.org/10.1177/104649649903000302
31. Nunkoo, D. K., & Sungkur, R. K. (2021). Team conflict dynamics & conflict management: Derivation of a model for software organisations to enhance team performance and software quality. *Global Transitions Proceedings, 2*, 545–552. https://doi.org/10.1016/j.gltp.2021.08.007
32. Abouaiana, A., & Battisti, A. (2022). Multifunction land use to promote energy communities in Mediterranean region: Cases of Egypt and Italy. *Land, 11*, 673. https://doi.org/10.3390/land11050673
33. Balaji, S., & Murugaiyan, M. S. (2012). Waterfall vs. V-model vs. Agile: A comparative study on SDLC. *International Journal of Information Technology and Business Management, 2*, 26–30.
34. Dybå, T., & Dingsøyr, T. (2008). Empirical studies of agile software development: A systematic review. *Information and Software Technology, 50*, 833–859.
35. Inayat, I., Salim, S. S., Marczak, S., et al. (2015). A systematic literature review on agile requirements engineering practices and challenges. *Computers in Human Behavior, 51*, 915–929.
36. APM. (2021). APM – The chartered body for the project profession. https://www.apm.org.uk/. Accessed 28 June 2022.
37. Agile Manifesto. (2001). Manifesto for Agile Software Development.
38. Conrad, E. (2011). Chapter 8 – Domain 8: Application development security. In Conrad EBT-EHC (Ed.), *Eleventh Hour CISSP Study Guide* (pp. 129–145). Syngress.
39. Thesing, T., Feldmann, C., & Burchardt, M. (2021). Agile versus waterfall project management: Decision model for selecting the appropriate approach to a project. *Procedia Computer Science, 181*, 746–756. https://doi.org/10.1016/J.PROCS.2021.01.227
40. López-Alcarria, A., Olivares-Vicente, A., & Poza-Vilches, F. (2019). A systematic review of the use of agile methodologies in education to foster sustainability competencies. *Sustainability, 11*, 2915.
41. Agile Alliance. (2021). Glossary – Extreme Programming (XP). https://www.agilealliance.org/glossary/xp/#q=~(infinite~false~filters~(postType~(~'post~'aa_book~'aa_event_session~'aa_experience_report~'aa_glossary~'aa_research_paper~'aa_video)~tags~(~'xp))~searchTerm~'~sort~false~sortDirection~'asc~page~1). Accessed 28 June 2022.
42. Hartson, R., & Pyla, P. (2019). Chapter 4 – Agile lifecycle processes and the funnel model of agile UX. In Hartson R, Pyla P. (Eds), *Agile UX design for a quality user experience* (pp. 63–80). Morgan Kaufmann, Boston.
43. McKnight, W. (2014). Chapter sixteen – Agile practices for information management. In W. B. T.-I. M. McKnight (Ed.), *Information management strategies for gaining a competitive advantage with data* (pp. 168–178). Morgan Kaufmann.
44. Institute for Sustainability. (2009). Institute for Sustainability – Home. https://www.instituteforsustainability.co.uk/index.html. Accessed 28 June 2022.
45. Fox, C. (2003). *The engineering and management of retrofit projects in the process industries*. European Construction Institute (ECI), Loughborough University.

46. Fojtik, R. (2011). Extreme programming in development of specific software. *Procedia Computer Science, 3*, 1464–1468. https://doi.org/10.1016/j.procs.2011.01.032
47. Staats, B. R., Brunner, D. J., & Upton, D. M. (2011). Lean principles, learning, and knowledge work: Evidence from a software services provider. *Journal of Operations Management, 29*, 376–390. https://doi.org/10.1016/j.jom.2010.11.005
48. Hron, M., & Obwegeser, N. (2022). Why and how is scrum being adapted in practice: A systematic review. *Journal of Systems and Software, 183*, 111110. https://doi.org/10.1016/j.jss.2021.111110
49. Hoda, R., Salleh, N., Grundy, J., & Tee, H. M. (2017). Systematic literature reviews in agile software development: A tertiary study. *Information and Software Technology, 85*, 60–70.
50. Powell, D. J. (2018). Kanban for lean production in high mix, low volume environments. *IFAC-PapersOnLine, 51*, 140–143. https://doi.org/10.1016/j.ifacol.2018.08.248
51. Rodov, A., & Teixidó, J. (2016). Blending agile and waterfall the keys to a successful implementation. In *PMI® Global Congress 2016—EMEA, Barcelona, Spain*. Project Management Institute.
52. Digital.ai. (2020). 15th state of agile report agile adoption accelerates across the enterprise.
53. Streule, T., Miserini, N., Bartlomé, O., et al. (2016). Implementation of scrum in the construction industry. *Procedia Engineering, 164*, 269–276. https://doi.org/10.1016/j.proeng.2016.11.619
54. Cano, E. L., García-Camús, J. M., Garzás, J., et al. (2021). A scrum-based framework for new product development in the non-software industry. *Journal of Engineering and Technology Management, 61*, 101634. https://doi.org/10.1016/j.jengtecman.2021.101634
55. Hicks, M., & Foster, J. S. (2010). *Adapting scrum to managing a research group*. University of Maryland, College Park.
56. Layton, M. C., & Morrow, D. (2018). *Scrum for dummies*. John Wiley & Sons.
57. Scrum. (2021). What is scrum? https://www.scrum.org/resources/what-is-scrum. Accessed 28 June 2022.
58. Layton, M. C., Ostermiller, S. J., & Kynaston, D. J. (2020). *Agile project management for dummies* (3rd ed.). John Wiley & Sons, Inc..
59. Schwaber, K., & Sutherland, J. (2020). *The scrum guide the definitive guide to scrum: The rules of the game*. Ken Schwaber and Jeff Sutherland.
60. Scrum Guide. (2020). *The 2020 Scrum GuideTM*. https://scrumguides.org/scrum-guide.html. Accessed 28 June 2022.
61. Maryna, Z., & Dmitriy, G. (2020). *Clear acceptance criteria for user stories with examples*. https://rubygarage.org/blog/clear-acceptance-criteria-and-why-its-important. Accessed 28 June 2022.
62. Chilvers, J., Pallett, H., & Hargreaves, T. (2018). Ecologies of participation in socio-technical change: The case of energy system transitions. *Energy Research and Social Science, 42*, 199–210.
63. Lowe, P., Ray, C., Ward, N., et al. (1998). *Participation in rural development: A review of European experience*. Center of Rural Economy.
64. van Heck, B. (2003, September). *Participatory development: Guidelines on beneficiary participation in agricultural and rural development* (2nd ed.). Rural Institutions and Participation Service, Rural Development Division Food and Agriculture Organization of the United Nations.
65. FAO. (2005). *An approach to rural development: Participatory and Negotiated Territorial Development (PNTD)*. Rural Development Division Food and Agriculture Organization of the United Nations (FAO).
66. Di Prata, O., & Ercoli, C. (2010). A key to understanding the challenges that face Italian project managers. In *PMI® global congress 2010—EMEA, Milan, Italy*. Project Management Institute.
67. Zein, O. (2016). *Culture and project management: Managing diversity in multicultural projects*. Routledge.

68. EDARA. (2021). Edara property management. http://edaraproperty.net/. Accessed 28 June 2022.
69. القناة الأولى المصرية. (2022) The first service building fully powered by clean energy inside the village of Kafr El-Sheikh. Arch.Ahmed Abouaiana reveals the details (in Arabic). https://www.youtube.com/watch?v=CmfAKqkLVfE. Accessed 28 June 2022.
70. IEE PassREg. (2015). IEE PassREg Passive House Regions with Renewable Energy Final Aggregated Monitoring and Evaluation Report Deliverable 2.5 Based on the Success Models and Monitoring reports from PassREg's frontrunner and aspiring regions.
71. PassREg. (2015). *Beacon project: Orduynenstraat Den Bosch*. https://passreg.eu/beaconProjectDetails.php?beacon_id=49&ref=beaconlist. Accessed 28 June 2022.

Part II
Buildings: Sustainable, Retrofitted and Renovated Buildings

Impact of Process Steps on the Performance of Heterojunction Solar Cells

Sergey Karabanov and Mikhail Reginevich

1 Introduction

Solar cells based on n-type crystalline silicon wafers with a passivated by hydrogenated intrinsic amorphous silicon surface and doped amorphous silicon (SHJ) layers have a number of advantages over cells made using conventional PERC technology [1]. These are a small number of process steps, a low thermal budget, and the possibility of reducing the thickness of the wafers. The most unique feature of this type of solar cells, which determines their high efficiency, is the layer of intrinsic amorphous hydrogenated silicon (a-Si:H). During the growth of the layer on the surface of the silicon wafer, the number of defects decreases, which leads to a decrease in recombination at the silicon–amorphous silicon interface (the so-called passivation). To obtain an efficient solar cell, it is important to get a a-Si:H layer that creates efficient passivation and efficient carrier transport, and to maintain these properties when exposed to subsequent technological steps. To create effective passivation and charge transfer, various techniques are used, such as the use of combined compositions with amorphous hydrogenated silicon oxide (a-SiOx:H) [2, 3], amorphous hydrogenated silicon carbide (a-SiCx:H) [4], high-temperature treatments [5], porous layers of intrinsic silicon, bilayers with different density [6], bilayers [7], and additional hydrogen plasma treatments [8]. Overlaying doped layers affects surface passivation, too [7]. The choice of PECVD process parameters: gas pressure, RF power, and dilution with hydrogen are associated with minimizing defects in the form of dangling bonds and preventing the formation of silicon epitaxial growth [9]. High ordered layer of intrinsic hydrogenated amorphous silicon with lower void density is beneficial to the solar cell parameters [10–12], but parameters of the layer deposition are such that any fluctuation can lead to epitaxial

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growth. Such reasons as interaction with holders and vacuum cups, incorrect timing after final HF dip until amorphous silicon deposition and overheating lead to the disappearance of silicon-hydrogen bonds on the wafer surface and create a starting point for epitaxial growth. The deposition of amorphous silicon bilayers, where the first layer is thin and characterized by a low density, and the second layer with a correspondingly high density, makes it possible to obtain high cell efficiency [13], but requires very careful surface preparation before deposition [14] and appropriate handling. Exposure to radiation during the sputtering of a transparent conductive oxide, mechanical stress during screen-printing of conductive pastes, laser radiation when opening contact windows in a mask for copper plating can damage the layers of amorphous silicon. Subsequent annealing increases the minority carrier lifetime, but the properties of the amorphous silicon layer will differ from the original ones. Therefore, it is necessary to carefully take into account the impact of process steps on the layers of amorphous silicon and noncontact nondestructive measurement methods to create high-efficiency solar cells [15, 16].

This work is devoted to the investigation of impact of process steps, such as a hydrogen plasma treatment, transparent conductive oxide sputtering and subsequent annealing, laser openings of contact window on the properties of a-Si:H layers and solar cells performance. We investigated impact on the level of surface recombination, the lifetime of minority charge carriers, layer microstructure, and solar cell parameters.

2 Experiment

For the manufacture of solar cells, n-type silicon wafers doped with phosphorus, 156.75 × 156.75 mm in size, 160 μm thick, with (100) orientation, with a resistivity of 1–5 Ohm cm were used.

For material characterization, layers of intrinsic amorphous silicon were deposited on both sides of polished c-Si wafer, in orientation (111), thickness of 560 microns.

After the process of removing the damaged layer by a KOH solution and texturing by KOH-based solution to obtain pyramids of 4–5 μm in size, the wafers were treated in solutions of H_2SO_4, HCl, H_2O_2 and dipped in diluted HF to strip off the silicon oxide. To determine the parameters of PECVD process during hydrogen plasma treatment, a series of intrinsic hydrogenated amorphous silicon layers were deposited. Deposition was conducted in an Applied Materials Precision 5000. The P5000 is equipped with parallel plate type reactor RF-PECVD (13.56 MHz excitation frequency). In this work, we used relatively high deposition rate of amorphous silicon, above 1.6 nm/s, and high hydrogen dilution. As a result of meeting two conditions such as a high deposition rate simultaneously with a high degree of dilution with hydrogen, a high-density electronic quality layer is generated, while the epitaxial growth of this layer is prevented. We set the ratio of silane to hydrogen as 1 to 5 at a pressure of 3.2 Torr and an RF discharge power of 250 mW/cm^2.

Processing with hydrogen plasma is a rather multifactorial process and the choice of the correct parameters is difficult. We were based on the idea of obtaining a relatively small number of ions with sufficient energy for implantation in the near-surface region. In this way, the etching rate can be reduced, which is critically important given the small thickness of the amorphous silicon layer and the relief of the textured surface. The power density and process pressure of hydrogen plasma treatment were chosen as the determining parameters and varied from 40 to 180 mW/cm^2 and from 2 to 3.2 Torr, respectively. The effective lifetime of minority carriers was chosen as an indicator and characterized by the QSSPC method using a Sinton WCT-120 flash tester. The resulting dependencies are shown in Fig. 1a. The best set of parameters is defined as a pressure of 2 Torr and an energy of 80 mW/cm^2.

Based on the assumption that amorphous silicon bilayers lead to better parameters of the intrinsic amorphous silicon layer [13], at the next stage, the thickness of the first layer was determined, after which this layer was subjected to hydrogen plasma treatment. The processing sequence is as follows—deposition of the first layer, starting with a thickness of 2 nm, then treatment with hydrogen plasma for 60 s, then deposition of the second layer until a total layer thickness of approximately 10 nm is obtained. As shown in Fig. 1b, at a small thickness of the amorphous layer, degradation occurs due to hydrogen plasma treatment, apparently caused by etching of amorphous silicon to a crystalline surface and subsequent epitaxial growth. At layer thicknesses of more than 4 nm, the layer parameters improve, the best lifetime is achieved in the range of 5–6 nm.

The following series of samples were fabricated with intrinsic and doped amorphous silicon layers using textured and polished substrates, one series with hydrogen plasma treatment, the other without treatment. The layers deposited in this process had a thickness of 10 nm for intrinsic silicon layers, for doped with boron—5 nm, for doped with phosphorus—15 nm. A Bruker IFS66 spectrometer was used to perform Fourier transform infrared spectroscopy of SI-H bonds microstructure of amorphous silicon layers on polished wafers. The same layers were deposited on both sides of the wafer to get decent signal-to-noise ratio.

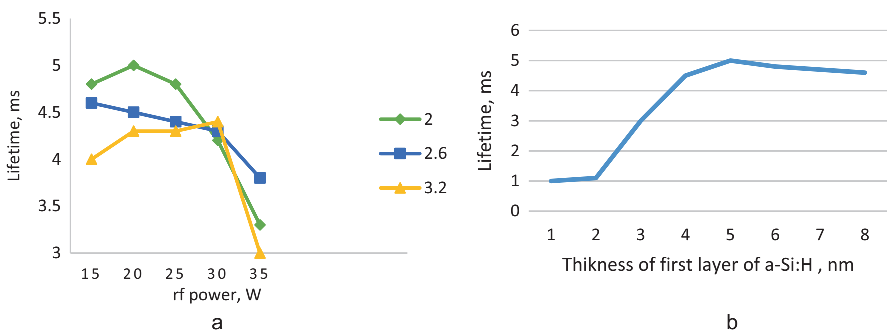

Fig. 1 (**a**) Dependence of minority carrier lifetime at injection level of e15 cm^{-3} on the RF power in chamber for different pressure levels (2, 2.6, 3.2 Torr). (**b**) Lifetime in dependence of the first layer thickness

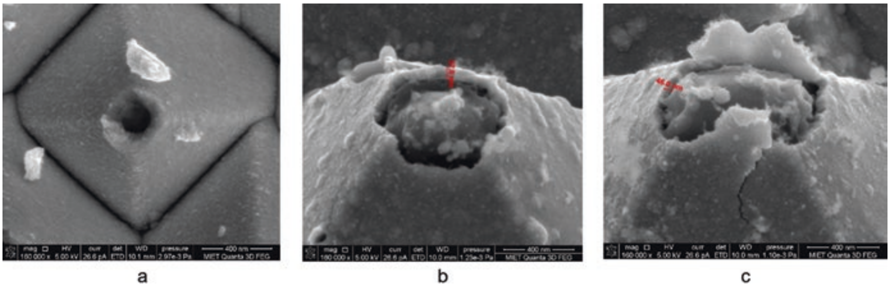

Fig. 2 Laser openings with different fluence: (**a**) 0.8, (**b**) 0.9, (**c**) 1 J/cm^2

Then, two groups were formed, for one group, 75 nm thick ITO layers were deposited by magnetron sputtering of a target consisting of 90% In and 10% Sn, and for the other group, 40 nm layers were deposited. MRC943 was used for sputtering. Layers of a selective seed layer of different thicknesses were formed on substrates with an ITO layer 40 nm thick, and then a layer of silicon nitride 40 nm thick was deposited. Further, these samples were used to open contact windows with ultra-short laser radiation pulses and to study the protective properties of the seed layer and the nature of damage to the amorphous silicon layer. To open the contact windows in the silicon nitride layer, we used an Avesta Theta 6 laser with a wavelength of 1033 nm, a power up to 6 W, a pulse duration of 270 fs TEM00, with a frequency of up to 100 kHz, and a Raylase scanning system, spot size 10 micron. The opening of the contact windows was performed with different fluence ranging from 0.5 to 2 J/cm^2 with a step of 0.1 J/cm^2 (Fig. 2a–c). For characterization, a fixed system with a microscope objective was used, which makes it possible to obtain a focused spot size of about 5 μm at the single pulse mode. For completing solar cells, copper plated contact grid was formed. I–V characteristics of fabricated cells were evaluated using a solar simulator under standard test condition (AM 1.5, 1000 W/m^2, 25 °C).

3 Results and Discussion

The etching rate of the amorphous silicon by hydrogen plasma is relatively higher than the etching rate of the areas of epitaxial growth. Thus, the area of the epitaxial growth regions increases after etching with hydrogen plasma, which negatively affects the subsequent growth of the amorphous silicon layer. As result, the quality of passivation deteriorates. Reduce in the etching rate with decreasing power and pressure is beneficial. Since the etching rate can exceed 1 nm/min, the process time is limited by the thickness of the amorphous layer. The choice of the treatment parameters with hydrogen plasma should be based on the following assumptions about the energy and concentration of hydrogen, as follows:

1. Avoid the appearance of a large number of low-energy hydrogen atoms providing etching.
2. It is preferable to obtain a small number of hydrogen atoms with a high enough energy so that they can penetrate into the near-surface region and then diffuse into the volume at the maximum allowable temperature.

Since the process of hydrogen plasma treatment for amorphization and hydrogenation of the layer is limited by the simultaneous etching process and etching rate can exceed 1 nm/min, especially of the edges and tips of the pyramids, it is necessary to search for compromise processing parameters. Si-H bonds incorporated in amorphous silicon in different manners. Si-H_2 bonds form nano-sized voids, while Si-H bonds are isolated. The FTIR spectra of intrinsic amorphous silicon layer and intrinsic amorphous silicon layers with intermediate hydrogen plasma treatment are shown in Fig. 3a. Gaussian-distributed absorption peak centered at wave numbers of 2000 cm^{-1} represents Si-H bonds (low-stretching mode) and peak at 2100 cm^{-1} represents Si-H_2 (high-stretching mode). Absorption by high-stretching mode increases noticeably after hydrogen plasma treatment. This means that the density of nanovoids in the amorphous silicon layer increased and this effect had a positive influence on the surface passivation. It is worth to note that hydrogen dilution prevents creation of Si-H_2 bonds during the applied process of deposition of ordered

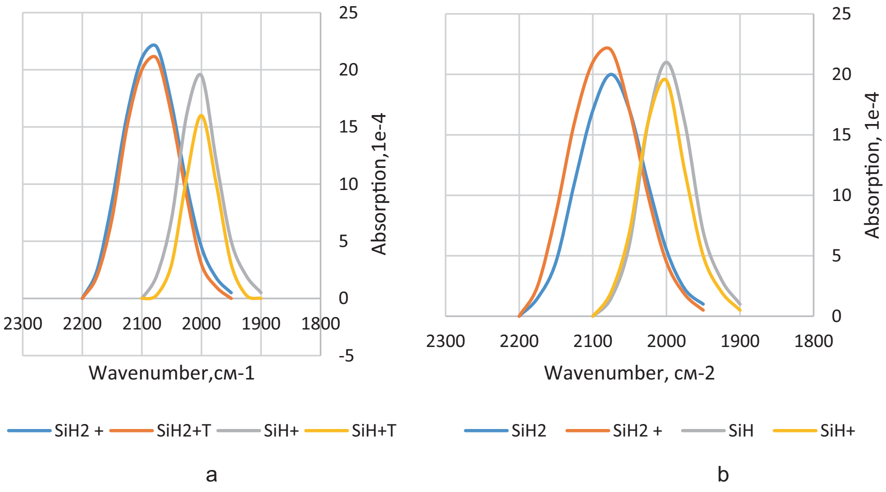

Fig. 3 (**a**) FTIR spectra of amorphous silicon with (+) and without hydrogen plasma treatment, fitted with Gaussian distributed peaks of absorption of Si-H_2 at wavenumber 2100 cm^{-1} and Si-H at wavenumber 2000 cm^{-1}. (**b**) FTIR spectra of amorphous silicon before and after sputtering of transparent conductive oxide and sintering, fitted with Gaussian distributed peaks of absorption of Si-H_2 at wavenumber 2100 and Si-H at 2000 cm^{-2}

intrinsic amorphous silicon. Layer with lower void density is preferable as a carrier transport channel. Since a layer of disordered intrinsic hydrogenated silicon with a high density of Si-H_2 bonds is not an effective carrier transport channel, its thickness is determined by the need to find a balance between the level of passivation and series resistance.

The change in the ratio of the number of Si-H and Si-H^2 bonds allows us to conclude that damage after ITO sputtering has a complex nature. Surface is damaged with high-energy argon ions, volume of the layer is damaged by UV radiation. Subsequent annealing leads to a redistribution of hydrogen in the layers of amorphous silicon (Fig. 3b). While the level of Si-H_2 bonds decreases insignificantly, the level of Si-H decreases largely, while Voc increases, which indicates a crystallization process without an increase in defectiveness, while maintaining the structure of nanovoids with boundaries passivated by hydrogen.

The opening of a contact window in a thin dielectric layer is possible by partial removal of the underlying layer. When exposed to a femtosecond laser pulse, because of multiphoton absorption, the ionization of the dielectric layer and the underlying metal layer occurs, after which energy is transferred to the lattice. Destruction of the lattice and evaporation occurs. The mechanism of removal of the dielectric film from the surface seems to be mainly associated with the removal of the evaporating metal by the flow. The nuclei of the process are local point defects, in which there is a high concentration of energy and the formation of an outflowing jet of evaporated metal begins.

An analysis of SEM images allows us to establish that for a textured surface of silicon wafer, the tips and, with a further increase in the energy density, the edges of the pyramids act as the starting points for the ablation process due to a faster increase in temperature and the formation of an outflowing jet. The very process of removal of the dielectric layer is determined by a combination of two mechanisms—the ablation itself and the explosive destruction of the dielectric layer by an evaporating metal flow. The SEM image (Fig. 2c) shows that the flow of the evaporated metal deformed the edges of the dielectric coating around the crater contour.

Damage to the layer of amorphous silicon occurs when the thickness of the seed layer is insufficient. It has been experimentally established for this type of structure, when using silver, that the layer thickness should exceed 400 nm.

At the same time, as the fluence increases, the size of the damaged area does not grow linearly (Fig. 4), which apparently indicates that the damage occurs in places where energy is concentrated—at the tops of the pyramids and on their edges. In these places, the energy level exceeds the energy level on the plane by a factor of 2; therefore, an increase in energy to a lesser extent does not lead to a proportional increase of the damaged area.

Thus, by changing the surface geometry, one can significantly change the level of admissible fluence.

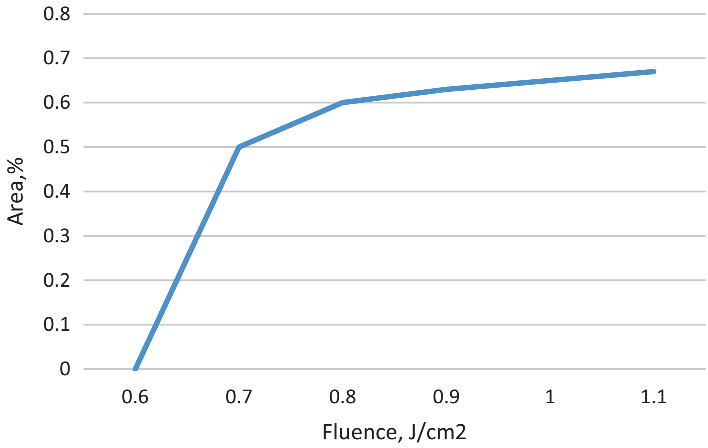

Fig. 4 Damage area in dependence of the fluence

4 Conclusion

The conducted research has the following results:

- Hydrogen plasma treatment makes it possible to amorphize and hydrogenate an amorphous silicon layer, thereby increasing the number of dihydride bonds and forming a layer structure with nanovoids.
- A layer of amorphous silicon with a large number of dihydride bonds is more stable to the effects of temperature and radiation during the manufacture of a solar cell than a layer with monohydride bonds.
- The optimal conditions for obtaining a stable, repeatable process of hydrogen plasma treatment of amorphous silicon layer are established.
- The process of removing the dielectric layer from the metal seed layer is determined largely by the geometry of the textured surface.

References

1. Roters, G., Krause, J., Leu, S., Richter, A., & Strahm B. Heterojunction technology. The solar cell of the future. https://www.meyerburger.com/user_upload/dashboard_news_bundle/da4c7a0b7c33e8e21ccddace78c6513b12cc727.pdf
2. Liu, W., Meng, F., Zhang, X., & Liu, Z. (2015). Evolution of a native oxide layer at the a-Si:H/c-Si interface and its influence on a silicon heterojunction solar cell. *ACS Applied Materials & Interfaces*, *9*, *7*(48), 26522–26529. https://doi.org/10.1021/acsami.5b07709. PMID: 26565116.
3. Fujiwara, H., Kaneko, T., & Kondo, M. (2007). Application of hydrogenated amorphous silicon oxide layers to c-Si heterojunction solar cells. *Applied Physics Letters, 91*(13), 133508–133503. https://doi.org/10.1063/1.2790815

4. Boccard, M., & Holman, Z. (2015). Amorphous silicon carbide passivating layers for crystalline silicon based heterojunction solar cells. *Journal of Applied Physics*, *118*(6), art. no. 065704.
5. Shi, J., Boccard, M., & Holman, Z. (2016). Plasma-initiated rehydrogenation of amorphous silicon to increase processing window of silicon heterojunction solar cells. *Applied Physics Letters*, *109*(3), art. no. 031601.
6. Liu, W., Zhang, L., Chen, R., Meng, F., Guo, W., Bao, J., & Liu, Z. (2016). Underdense a-Si:H film capped by a dense film as the passivation layer of a silicon heterojunction solar cell. *Journal of Applied Physics, 120*(17). https://doi.org/10.1063/1.4966941. ISBN: 0021-8979.
7. Sai, H., Chen, P., Hsu, H., Matsui, T., Nunomura, S., & Matsubara, K. (2018). Impact of intrinsic amorphous silicon bilayers in silicon heterojunction solar cells. *Journal of Applied Physics, 124*, 103102. https://doi.org/10.1063/1.5045155. ISBN: 0021-8979.
8. Mews, M., Conrad, E., Kirner, S., Mingirulli, N., & Korte, L. (2014). Hydrogen plasma treatment of amorphous/crystalline silicon heterojunctions. *Energy Procedia, 55*. https://doi.org/10.1016/j.egypro.2014.08.066
9. Fujiwara, H., & Kondo, M. (2007). Impact of epitaxial growth at the heterointerface of a-Si:H/c-Si solar cells. *Applied Physics Letters, 90*, 013503. https://doi.org/10.1063/1.2426900. ISBN: 0003-6951.
10. Augusto, A., Herasimenka, S., King, R., Bowden, S., & Honsberg, C. (2017). Analysis of the recombination mechanisms of a silicon solar cell with low bandgap-voltage offset. https://doi.org/10.1063/1.4984071. ISBN: 0021-8979.
11. Kim, S., Dao, V., Shin, C., Cho, J., Lee, Y., Balaji, N., Ahn, S., Kim, Y., & Yi, J. (2012). Low defect interface study of intrinsic layer for c-Si surface passivation in aSi:H/c-Si heterojunction solar cells. *Thin Solid Films, 521*, 45–49. https://doi.org/10.1016/j.tsf.2012.03.074
12. Zhao, L., Diao, H., Zeng, X., Zhou, C., Li, H., & Wang, W. (2010). Comparative study of the surface passivation on crystalline silicon by silicon thin films with different structures. *Physica B, 405*, 61–64. https://doi.org/10.1016/j.physb.2009.08.0
13. Ru, X., Qu, M., Wang, J., Ruan, T., Yang, M., Peng, F., Long, W., Zheng, K., Yan, H., & Xu, X. (2020). 25.1% efficiency silicon heterojunction solar cell with low deposition rate intrinsic amorphous silicon buffer layers. *Solar Energy Materials and Solar Cells, 215*, 110643.
14. Angermann, H., Henrion, W., & Rebien, M. (2004). Wet-chemical preparation and spectroscopic characterization of Si-H interfaces. *Applied Surface Science, 235*, 322–339.
15. Koshelev, O., Vasiliev, N., Reginevich, M., & Shnaidshtein, I. (2018). Non-contact detection of photosensitivity inhomogeneities of HIT-type heterostructures based on α-Si: H/c-Si, Materials of the XVI All-Russian Seminar "Wave Phenomena in Inhomogeneous Media" named after A.P. Sukhorukov (Waves 2018). *Bulletin of the Russian Academy of Sciences: Physics*, *82*(11), 1421–1424, 1558–1562. https://doi.org/10.3103/S1062873818110138
16. Reginevich, M., Karabanov, S., & Bugrov, A. (2020). Investigation of silicon nitride as a mask for a plated grid of heterojunction solar cells. *Vestnik Rjazanskogo gosudarstvennogo radiotehnicheskogo universiteta, 74*, 129–135. https://doi.org/10.21667/1995-4565-2020-74-129-135. (in Russian).

Active and Passive Energy Efficiency Systems Compatible with Traditional Buildings in Palestine

Yazan Shamroukh and Eyad AbuAlZullf

1 Introduction

Heritage buildings that are considered to have important architectural and cultural qualities worthy of preservation are usually excluded from legislation regarding minimum energy performance requirements. The potential for retrofit of cultural heritage buildings is significant due to the current composition of the building stock in Palestine and the preferred attitude of the public toward the older stock. Over the last decade, there is a growing interest on the energy retrofit of historic buildings, as they do not always comply with contemporary concepts regarding thermal comfort [1] and face the challenge of resilience in the light of climate change [2]. Therefore, as entirely passively conditioned buildings are rarely attainable, a balanced interplay between passive and active building elements is often the final goal of an efficient retrofit strategy. Passive systems collect and transport heat by nonmechanical means and operate on the energy available in the immediate environment.

In contrast, active systems import energy, such as electricity, to power mechanical systems (e.g., heat pumps). Buildings that incorporate passive features combined with basic low-tech active elements, e.g., fans, are termed hybrid buildings. Older buildings are capable of adapting to the new energy efficiency (EE) norms; therefore, the challenge is to achieve the desired effect without damaging the architectural and historical value of buildings, while retaining the feasibility of the investment [3]. The preliminary evaluation of the climatic potential of a buildings' location is a key tool for planning both the enhancement of passive design aspects and the effective upgrade of the insulation capacity of the building envelope. The

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incorporation of active systems or energy microgeneration systems are also gaining ground over the last years, yet integration issues may arise in the case of heritage buildings [4].

Available design strategies and active energy systems should be considered with the objective to lower energy consumption while enhancing the comfort of occupants, although comfort is very difficult to quantify in exact values that satisfy everyone [5]. Indoor comfort includes a number of parameters of the indoor environment, such as temperature humidity, air quality, lighting, and noise levels. In this context, there have been attempts to study the indoor environment holistically. In this study, all aspects of comfort that can be improved were considered when selecting scenario for implementation.

The work done on this case study is part of the BIM for Energy Efficiency in Public sector (BEEP) project, which aims to foster the replicability of the methodologies and solutions suggested and developed in the cross-border case studies widespread in MED area, strengthening the cooperation among EU and MP countries, and disseminating a highly advanced AEC industry standard.

2 Building Construction

The case study building was constructed between the years 1899 and 1910 by the owner himself. It is a large-scale standalone-building composed of three floors surrounded by an open area. The building was constructed over several successive periods out of traditional material used at that time and the structural systems used reflect the advancement of building techniques that developed and changed during the short period of time the building construction took place (Fig. 1).

Fig. 1 Case study building

Stone walls were built using 2 layers of finely textured stone, where each layer is around (25–35) cm thick, and the layer between was filled with small stone pieces and soil fill from the surrounding area. The total thickness of the walls varied from 80 to 120 cm.

The ground floor consists of traditional cross vaults and in places composite barrel-cross vaults that distribute the loads of the ceilings onto the thick stone walls. In the upper first and second floors, the cross-vault system was replaced with a flat concrete with steel I-beams that transfer the loads to stone arches and distribute the loads onto the stone walls. Morcos palace was one of the first buildings in Bethlehem to witness such development in construction techniques.

The building consists of several internal partitions, some are authentic and others are of later addition or even recent. There are several types of transparent envelope object due to the different stages and the interventions that occurred to the building; most of the windows are traditional wooden windows with clear single glass, while other windows have steel frame, mainly these windows have air infiltration and some water leakage.

The climate of the Palestinian Territories is influenced by the Mediterranean climate where long, hot, dry summer and short, cool, rainy winter climate conditions prevail. Climatic variations occur in the different topographical regions. Though relatively small in area, the West Bank enjoys diverse topography, soil structure, and climate conditions [6].

3 Energy and Environmental Analyses Process

3.1 Visual Survey

Several visits to the case study building location were done, and all the data collected about the building use, number of employees, working hours, function of rooms, electric consumption, electrical appliances, ventilation, daylighting, humidity, and assessment of the existing systems.

3.2 Field Analyses

3.2.1 Heat Flux Meter Analysis

The heat flux meter analysis implemented on the building elements by using "FluxTeq" heat flux sensor, which has a sensitivity of 150 uV/W/m^2. The test duration was at least 48 hours for each part.

The R-VALUE was measured using "FluxTeq R-value measurement unit," which includes the heat flux sensor and temperature sensors (Fig. 2).

Fig. 2 R-value measurement

3.2.2 IR Thermography

Through using the thermal imager camera, moisture and water damage in building elements were detected. Spots of the moisture and humidity effect were in different places in the building, most of them were in the second and first floor. However, some changes recently were made in the building by removing the plastering layer in the second and first floors in order to show the stone beauty and to get rid of the mold on the internal layer of the wall.

3.2.3 Lighting

The digital exposure meter was used to measure light levels in each room of the building, in order to compare the results with the recommended values of LUX needed for each room and activity. The measured values were taken from different positions in some rooms.

The building contains fluorescent, LED, and incandescent lights inside and outside, most of them in a good condition, while there are a few disabled bulbs. The building gets a good quantity of natural light into the rooms; however, the artificial light is not distributed properly in the rooms.

4 Design Interventions Scenarios

A balanced interplay between passive and active building elements is often the final goal of an efficient retrofit strategy. However, in the case of historic buildings, the challenge is to achieve the desired effect while respecting the architectural and historical value of the built heritage and retaining the feasibility of the investment [3].

4.1 Description of the Proposed Interventions

The characteristics of the proposed interventions for the energy and environmental improvement of the Morcos Nassar Palace are described below.

4.1.1 Adding Thermal Insulation Material for the Second Floor's Ceiling

The intervention proposed will be compatible with the building heritage components and will not affect or change the existing interior view, but it will reduce thermal losses through building envelop.

The existing layers of the second floor's roof are: Layer 1 (Outer layer): Stone tiles, Layer 2: Cast concrete, and Layer 3 (Inner layer): plastering, with U-Value = 3.138 W/m^2. K. The proposed intervention adds Layer4: (Insulation Material), and the expected U-Value of the roof after thermal insulation is 0.4 W/m^2. K. The total cost of the insulation is 1860 euros, which covers 155 m^2.

4.1.2 Replacing Fluorescent Lamps with LED Lamps and Adding Motion Sensors

The new lamps and bulbs for the building provide better lighting conditions with less electrical power consumption, which will also reflect the beauty of the interior building. Replacing inefficient incandescent bulbs and CFLs with LED lamps would result in 50% energy savings or more. Estimated cost of the intervention is 548.5 euros, including the motion sensors.

4.1.3 Install VRF System

The building uses split air-conditioning system for heating and cooling; there are 11 air-conditions in various rooms, and each one has an indoor and outdoor unit. The new HVAC system provides better heating and cooling conditions, taking into consideration balancing comfort and preservation, and this will also reflect the beauty of the building from outside by reducing number of external units for the existing system. The total estimated cost of this intervention based on previous experiences is 13,000 euros.

4.1.4 Installing Solar Water Heaters on the Roof

Solar water heating systems are used extensively in Palestine and technicians are well experienced in installing such systems. The current water heater was added at a later stage, and the solar thermal collectors are in bad condition. There will be no negative effect or impact on the heritage building by installing and improving the solar water system on the roof. It is suggested to install four evacuated tube collectors provided with CPC reflectors, which enhance their efficiency. Hot water storage tank of 150 liter provided with electric heating coil will replace the 80-litre existing one. The new tank will be positioned on the same location and using same electrical and pipe connections. Total cost of solar system improvement amounts to 3300$.

4.1.5 Install Photovoltaic System on the Roof

This intervention aims to produce electrical energy from renewable energy, and it will not affect the materials of the building. This intervention will be done taking into consideration the beauty of the heritage building and preserving its materials. The PV system will be connected with the power source from the electrical distribution company in the building, by applying net metering scheme. Using solar energy can have a positive and indirect effect on the environment when solar energy replaces or reduces the use of conventional energy sources that have larger effects on the environment. The estimated cost of the intervention is 950€/kWp, the total cost of 20 kWp will cost 19,000 €.

Technical characteristics of proposed PV system are shown in Table 1 (Fig. 3).

Table 1 Characteristics of suggested PV system

Typology	Monocrystalline silicon
Scheme	Grid connected
Module efficiency	21.4%
Number of modules	31
Module power	650 W
Tilt angle	22°
Azimuth	30°
Kilowatt-Peak	20.15 kWp
Position	On roof, south facing
Expected annual energy production	33,000 kWh/y

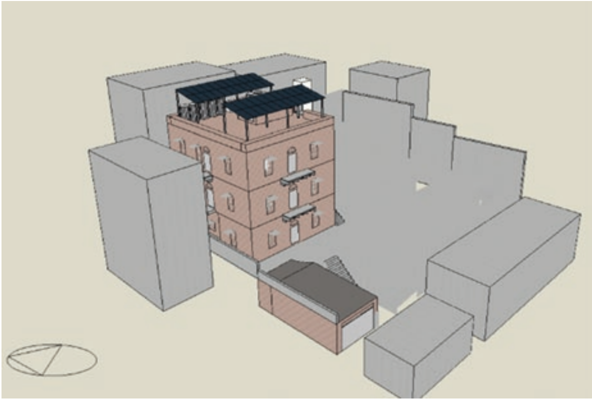

Fig. 3 PV system

Fig. 4 Revit model

5 EE-HBIM Model Development

BIM software acts as a core database of information of multiple dimensions, classifying the building's operational, financial, managerial, ecological, and maintenance attributes and functions. However, exporting BIM data for Building Performance Simulation (BPS) applications depends on data exchange formats and their subsequent file standards compatibility. When information is fully defined and appropriately registered, a single export can save a significant amount of time, effort, and potential error occurrences, as compared to reproducing the respective Energy Model in a native BPS environment [7] (Fig. 4).

Streamlining the simulation workflow through BIM and applying numerical simulation to historical buildings are two highly experimental research fields. To evaluate the implications of design intervention on decay process, environmental behavior and energy consumption of the building, specific numerical simulations calibrated on energy bills and environmental monitoring were used.

6 Results

These outputs contain the results of the energy performance and environmental simulations of the case study buildings under the two scenarios, featuring both static and dynamics evaluations.

The short-term scenario will ensure the comfort within the building and the more effective intervention from energy efficiency point of view, with ephemeral and cost-efficient interventions. The middle-term one involves a deeper renovation that will focus on introducing new and more efficient technologies. Table 2 gives a summary of the investigated scenarios and their classification.

6.1 Description of the Scenarios

6.1.1 Short-Term Scenario

The short-term scenario involved the thermal insulation intervention and the shading elements as passive interventions, and the replacement of the fluorescent lamps with LED in order to reduce the lighting consumption, in addition to the renewable energy systems related to water heating and generating electricity.

6.1.2 Middle-Term Scenario

The scenario included all the previous interventions, in addition to substituting the existing glazing with triple clear glazing, and installing a VRF system rather than the existing one.

Table 2 Classifications of interventions

Intervention	Short-term scenario	Middle-term scenario
PS5P01: Thermal insulation	X	X
PS5P02: Windows substitution		X
PS5P03: Shading elements	X	X
PS5A01: Replacement of fluorescent lamps with LED lamps and adding movement sensors	X	X
PS5A02: Install VRF system		X
PS5R01: Installing solar water heaters on the roof	X	X
PS5R02: Install photovoltaic system on the roof	X	X

Table 3 Assessment of proposed energy retrofit interventions

Parameters	Existing building	Short term	Middle term
Total primary energy EPtot [kWh/annual]	38,365.50	28,900.59	25,700.23
Total primary energy EPtot [kWh/m^2/annual]	94.48	69.76	62.48
Primary energy consumption percentage reduction		24.67%	33.01%
Electricity consumption, kWh/year	38,365.50	28,900.59	25,700.23
PV electricity [kWh/year]	0.00	33,000 20kWp system	28,875 17kWp system
Overall investment cost [€]	/	28,208	51,358
Simple payback time [year]	/	4.31	8.99
Payback time	/	5.05	12.24

Comparative assessment of the proposed energy retrofit scenarios is presented in Table 3. Note that the generated power from the photovoltaic system will cover the electricity consumption.

7 Conclusion

This study will contribute in building a database of both active and passive energy efficiency technologies compatible with the international restoration charts and therefore suitable for energy improvement intervention on historical buildings, while providing the comfort conditions inside the building.

The results obtained by using DesignBuilder software is very realistic and gives very promising results for integrating renewable energy solutions with energy efficiency measures.

The economic analysis brings attractive figures for investment. The project has a payback period of 4.31 years. This project can bring a yearly fuel saving of 38,365.5 kWh and the GHG emission reduction of 25.86 tonnes (Gross for 25 years is 647 tonnes) of carbon dioxide which is equivalent to 8.1 tonnes of waste recycled per annum, 2.6 hectares of forest absorbing carbon, 54.1 barrels of crude oil not being consumed, 9951 liters of gasoline not consumed, and 3.3 light trucks and cars not being used. Thus, the proposed project is both environmentally friendly and economically feasible.

Finally, this project and according to the simulation and results is achieving nearly zero-energy building (ZEB) with a 102% fuel consumption reduction and GHGs emissions reduction.

References

1. Martínez-Molina, A., Tort-Ausina, I., Cho, S., & Vivancos, J.-L. (2016). Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews, 61*, 70–85.
2. Hudobivnik, B., Pajek, L., Kunič, R., & Košir, M. (2016). FEM thermal performance analysis of multi-layer external walls during typical summer conditions considering high intensity passive cooling. *Applied Energy, 178*(September), 363–375.
3. Ding, G. (2013). Demolish or refurbish – Environmental benefits of housing conservation. *Construction Economics and Building, 13*(2), 18–34.
4. Historic England. (2018). *Energy efficiency and historic buildings, how to improve energy efficiency*. Historic England.
5. Hegger, M., Fuchs, M., Stark, T., & Zeumer, M. (2012). *Energy manual: Sustainable architecture*. Walter de Gruyter.
6. Applied Research Institute- Jerusalem (ARIJ). (1999). *The status of the environment in the West Bank*. Applied Research Institute-Jerusalem.
7. Pinheiro, S., Donnell, J., Wimmer, R., Bazjanac, V., Muhic, S., Maile, T., Frisch, J., & Treeck, C. (2016). *Model view definition for advanced building energy performance simulation*.

Proposal of a Multiscalar Assessment Framework to Guide Renovation Actions Toward a More Resilient Built Environment

Fabio Conato, Valentina Frighi, and Laura Sacchetti

1 Introduction

Despite the long-lasting debate on the strategies to shift toward a more sustainable construction sector, the latest pandemic emergency has served as a wake-up call for leaders and the scientific community, as well as for citizens, on the urgency to drive the built environment toward a more resilient future. Among the negative consequences on the global building market, the Covid-19 pandemic has to be credited for the acceleration of the process through the introduction of new and consistent financial investment programs. After 2020, the European building sector saw an unprecedented rise in energy efficiency investments given, on one hand, by the growth of expenditure and, on the other, by the announcements of new government support policies [1]. This drift was notably needed as still, in spite of the improvements, "buildings sector energy intensity needs to drop nearly five times more quickly over the next 10 years than it did in the past five to be in line with the Net Zero Emissions by 2050 Scenario" [2]. Through the past decades, the AEC (Architecture, Engineering and Construction) industry has created a great *environmental impact*, reaching in 2020 the 36% of the global final energy demand and 37% of related CO_2 emissions compared to other sectors [3] (Fig. 1). Considering the need to fill this gap and the leading role of building and construction as one of the major economies in Europe, it appears then necessary to hereafter grant reasonably large expenditure in this sector.

In addition to this, it is essential to consider that, at the moment, 75% of the European building stock is energy inefficient [4], most of which will still be standing in 2050 [5]. For this reason, in the past few years, a rising interest toward

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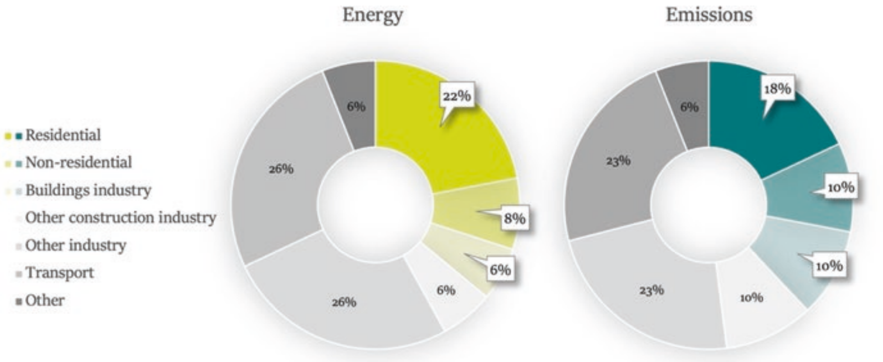

Fig. 1 Buildings and construction's share of global final energy and energy-related CO_2 emissions in 2020. (Data source: adapted from UN Environment Programme, 2021)

Table 1 Investments in the renovation sector in Italy

Renovation investments[a]	2019 (%)	2020 (%)	2021 (%)
Residential	1.8	−6.8	25.2
Nonresidential private	1.6	−12.4	15.2
Nonresidential public	7.3	10.9	14.3
Public	16.4	2.7	11.9

Data source: CRESME, 2021
[a]Annual percent variance

renovation has developed in Europe, including the Mediterranean region,[1] leading to the promotion of communitarian directives and, on the other hand, to increasing investments in this sector [6] (Table 1). However, the renovation rates of the building stock in Europe are quite low: between 2012 and 2016 the average energy renovation for residential and nonresidential buildings was around 5.9% (Table 2). Even though the Mediterranean countries show a higher renovation rate compared to the European average, the EU reports indicate that the current pace needs further acceleration [7].

Dating back to the deep-seated causes that led to Green Deal definition, current renovation approaches mainly aim at coping with the consequences of long-standing constructions, thus reducing their environmental impact in terms of energy efficiency and emission reduction. Nonetheless, most of the building stock has proven to be inadequate to meet the current requirements appointed by their intended use and by the latest national directives [8], particularly when considering the functional and spatial needs related to unpredictable events, such as the latest pandemic

[1] In this paper, Italy, Spain, Portugal, France (partially) and Cyprus, Malta and Greece (completely) are considered Mediterranean countries, according to the EU definition of "Mediterranean Region." (https://ec.europa.eu/environment/nature/natura2000/biogeog_regions/mediterranean/index_en.htm).

Table 2 Energy renovation rates of the European building stock 2012–2016

		Total (%)	Below threshold (%)	Light (%)	Medium (%)	Deep (%)
Residential	EU	12.3	7.1	3.9	1.1	0.2
	Med region	14	8.9	3.5	1.3	0.2
Nonresidential	EU	9.5	4.1	3	2.1	0.3
	Med region	15.6	6.6	4.6	3.8	0.6

Data source: elaboration on EU, 2019

emergency. In order to respond to the soaring demand for "temporary spaces," able to shift between uses [9], it appears crucial to strengthen the functional reversibility of the existing building stock through the upcoming interventions. The current and approaching investment surge has to be taken as a great opportunity to improve the *energy efficiency*, *flexibility*, and *resilience* of the building stock against unpredictably changing circumstances, thus reducing its functional and technological obsolescence.

In the outlined scenario, this contribution aims at introducing the *conceptual framework for the definition of a decision support tool*, intended to guide public administrations, professionals, and decision-makers by providing useful information in the early design phase, in order to predict—through the assessment of the initial condition—the adaptability of existing buildings to accommodate flexible configurations and adaptive technologies toward a more resilient built environment.

2 The European Legislative Framework

After the Paris Agreement (2015) set the target of arresting global warming to 1.5° [10] and later on the Emissions Gap Report relocated it more realistically to 2° (2019) [11], the European Green Deal (2019) introduced new measures to achieve carbon neutrality by 2050 [12], and numerous European directives addressing energy efficiency (EE) were issued. Considering the high energy demand and related emissions of the existing building stock, the improvement of energy efficiency through new renovation approaches is a priority. In 2018, it was decided for the amendment of the previous so-called Energy Performance of Buildings Directives (EPBD)—Directive 2010/31/EU and 2012/27/EU on buildings energy efficiency—introducing the new *Directive 2018/844/EU* instead [13]. The latter sets minimum energy performance requirements for new and existing buildings undergoing renovation. This regulatory framework also obligates EU Member States (EU MSs) to conceive long-term renovation strategies for the decarbonization of the building sector within the next 30 years. Notably, the EU Commission has revised this regulation, proposing a novel version of EPDB in 2021, which set out the new target of 60% emission reductions in the building sector by 2030, in comparison to

2015 [14]. In this occasion, it was also proposed that public administrations should be required to renovate at least 3% of their total owned building floor area each year.

This upgrade was requested because of the awareness, arisen in 2019 within the *2030 Climate target plan*, that the current European policy framework would not be enough to meet the Paris Agreement commitments and reach the awaited 2050 goals [3]. This led to raising the European climate ambition to a 55% emission reduction by 2030.

In 2020, as a flagship of the Green Deal, the European *Renovation Wave* directly addressed this need, proposing to double annual energy renovation rates throughout the next 10 years and to encourage deep renovations [15]. In the same context, the EU Commission promoted the implementation of Digital Building Logbooks (DBL), integrating data of the already trialed Building Renovation Passports and of the Energy Performance Certificates, containing information on the overall building performance.

These actions need parallel measures to introduce new and appropriate financial instruments, aimed at supporting the abovementioned ambitious goals toward climate change adaptation and mitigation. In Europe, many funding instruments are now available to provide for effectual interventions. Among these instruments, such as European Structural and Investment Funds (ESIF), the European Fund for Strategic Investments (EFSI), and the Cohesion Policy, the *National Recovery and Resilience Plan* (NRRP) allocates relevant economic resources through unprecedented additional public fund injections, to foster the renovation process. It has to be noticed that, compared to other EU MSs, the Mediterranean countries investments in the sector represent the most significant volumes, with consistent procapita funding [16] (Fig. 2). For this reason, especially in the abovementioned area, the NRRP represents a unique opportunity not only to make a substantial step toward a more sustainable built environment, but also to unlock as many co-benefits as possible through the funded renovation interventions.

3 Current Approaches Toward a "Flexible" Adaptability in Buildings

Aside from the need to intensify deep renovation actions, owing to the unpreparedness of the public and residential spaces to readjust in accordance with the evolving cultural and societal context—as well shown during the latest emergency occurrence—it is necessary to acknowledge the role of flexible design in renovations, not only to modernize the building stock to meet present needs, but also to prepare it to accommodate new functions in the upcoming years. In fact, all factors and circumstances around a building constantly alter its operational conditions: the way a building is used can change drastically from one day to the next, or even during the day; so, how comfortable and enduring would buildings be if they could adapt and react flexibly to these changes [17]? Adaptability in buildings can be related to the

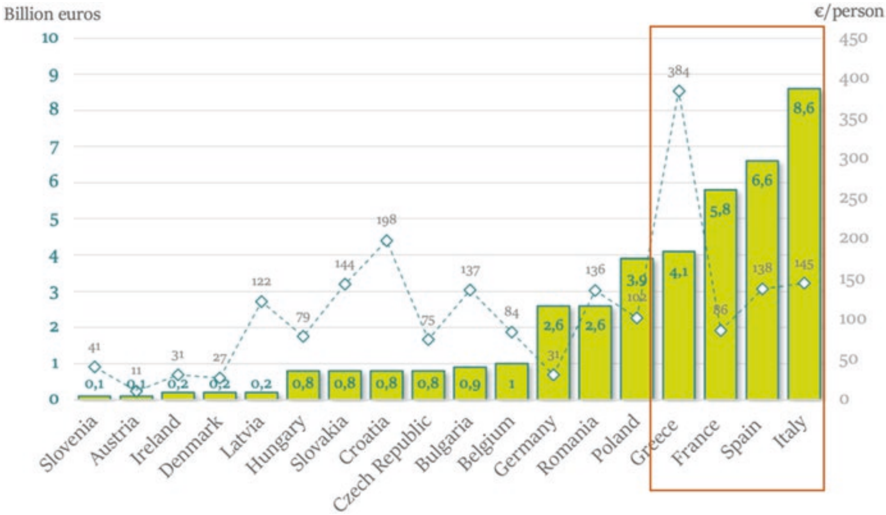

Fig. 2 EU MSs renovation funding in National Recovery and Resilience Plans. (Data source: adapted from E3G, 2021)

ability of spaces and internal layout to meet requirements and end-users' expectations, but it can also be intended in terms of performance, thus being related to the building envelope but not only limited to it.

Since 2018, the European Union has aimed at promoting the adoption of advanced technologies to implement the *adaptivity* of the building stock; in particular, the abovementioned EPBD 844/2018/EU introduced the so-called *Smart Readiness Indicator* (SRI) to classify the level of "intelligence" of a building, in order to foster the adoption of smart building technologies within the construction sector [13]. In addition, the SRI is to become part of the data collected by the Digital Building Logbook, intended as a digital comprehensive and dynamic repository of all building information to be exchanged through all involved stakeholders [18]. In this case, gathering the building Smart Readiness Indicators contributes to monitoring the progress of the construction sector toward the European climate goals.

It is of common knowledge that the integration of smart technologies within complex systems such as buildings and/or districts allows to reach, even partially, an improved level of adaptability, thus creating benefits for citizens in terms of well-being, environmental quality, and intelligent development [19]. Nevertheless, although the concept of intelligent, smart building(s) originated in the 1980s [20], there is no commonly accepted definition of them. According to the document issued by the EU Commission, it is possible to claim that through the adoption of smart technologies, a building can: manage and control RES, adapt to the grid conditions, communicate with other buildings, and actively respond in an efficient manner to any changing conditions in relation to the operativeness of the technical building systems or the external environment and the demands from the building occupants [21]. Due to the rapid pace triggering technological innovations, advancements have been made in the field of the so-called cognitive buildings, referring to the process of acquiring knowledge and understanding. Such learning ability can be achieved through Artificial Intelligence (AI) thanks to Machine Learning (ML) algorithms, sensory technology, inferences, but also through shared patterns between occupants and buildings. Similar processes can be applied to renovations, leveraging the Digital Twin (DT) technology, used to assess the outcome probabilities of various scenarios by running multiple simulations on a dynamic virtual representation depicted as an interactive 3D model. Rather than just making predictions, this allows to anticipate and predict future events in an automated way, making buildings able to respond to current and prospective demands without the need for inputs of human nature. However, there is still a lack within the current legislation to address the "smart retrofitting requirements" [21] and, in spite of the definition of the SRI, there is the need to develop, or at least integrate within renovation approaches a proper *guideline* as a basis to increase and implement the smartness in buildings toward their adaptivity.

A similar approach can be identified when looking at the concept of *resilience* within the built environment. The EU describes it as "the ability of an individual, a household, a community, a country or a region to withstand, to adapt, and to quickly recover from stresses and shocks" [22], thus including in this definition the possibility to adapt to predictable or unpredictable changing circumstances. However, resilience is generally intended as preparedness to avoid climate-related disasters, thanks to adaptation and mitigation actions [23]. In this regard, the urban environment has been increasingly exposed to intensifying risks, because of the more frequent escalation of weather events and the growing urban population, and buildings and infrastructure are frontline to cope with the consequences of these issues [24]. Improvements in urban resilience are fundamental to protect people living in cities, but also to safeguard public and private investments in many sectors. To evaluate the current hazard risks, in order to guide the governance of these aspects, the International Finance Corporation (IFC) has conceived a *Building Resilience Index* (BRI), capable of assessing the standing construction exposure to hazards and the relative capacity to properly respond [25]. This online assessment framework for the building sector aims at addressing the current poor implementation of resilience plans within cities, derived from the lack of consistent and reliable data on climate risks.

4 The Conceptualization of the Multi-criteria Support Tool

Stemming from the concept of the twin transition, the current approaches expect future interventions, including renovations, to comply with the green and digital requirements. However, considering the premises on the growing obsolescence of the built environment, the implementation of adaptivity and resilience is not satisfactory to prepare the urban setting for the next generation needs. In view of the extent of the upcoming challenges, but also of the financial opportunity given by the

NRRP, it would be essential to reconsider and enhance the role of design, even during preliminary phases, in future renovations pathways, in order to fully maximize the generation of *co-benefits*, not only in terms of environmental impact, but also of flexibility and resilience of the overall building stock.

Therefore, professionals involved in renovation processes are asked to adopt more *holistic approaches*, to first evaluate the level of obsolescence and reversibility of existing buildings, and then embrace the challenge of improving their performance through specific targeted actions.

Hence, such pathways entail further complexity: they should include the introduction of smart building components and address disaster preparedness, without forgetting to guarantee flexible use and streamline future functional and spatial evolutions. The foreword of *operational tools* could indeed facilitate the implementation of such virtuous strategies within the oncoming renovation programs. To this end, the following section introduces the assessment framework proposed for the definition of a *decision support tool* (DST), aimed at simplifying the evaluation process during the early design phases.

4.1 The Aim of the Proposed Decision Support Tool

The fine-tuning of the proposed decision support tool has been possible thanks to previous research activities on the topic of existing buildings, aimed at evaluating their level of reversibility to current standards. The final aim of this tool is to assess the adaptability of the existing building stock to be refurbished through flexible solutions, in order to increase its functionality and downscale future obsolescence phenomena, thus reducing consequent maintenance actions. In all design processes, including renovations, the planning and early phase play a significant role, especially in analyzing the viable options in order to embrace the most favorable actions. During such stages, the proposed tool would allow, on one hand, to evaluate the *feasibility* of the renovations and, on the other, to predict possible design solutions leading to the relative expected *impact* of the action in providing the final desirable level of flexibility. Such parameters, expressed through a numerical index, could inform professionals, public administrations, private owners, and decision-makers on the most effective choices of intervention, in a sort of simulating what-if scenario, providing information about the most appropriate sites to address with the renovation, so as the most convenient technical solutions to be adopted.

It has been well established that DSTs should consider multiple factors, in order to carry out a more thorough analysis and produce more consistent results. For this reason, the proposed tool, regardless the specific object of interventions to which it could be addressed, is based on the four different scales, considered as influential factors in each project outcome, as follows: (1) *urban site*, (2) *building aggregate*, (3) *spatial units, and* (4) *construction methods and materials*. The development of the study across multiple scales, in fact, enables to identify the assets and criticalities of the existing pre-conditions, thus outlining the strengths, weaknesses, and constraints of the potential intervention, located at different levels. This serves the purpose of establishing which are the most "ductile" scales, to be leveraged for more extensive transformations, and which are the "tightest" scales, that for plausible reasons could not undertake a comparable degree of renewal. This approach promotes the employment of *compensation strategies*, addressing the most operable scales in order to reach the projected flexible outcomes.

As soon as the feasibility and specificity of each project site have been identified, the proposed approach envisions the definition of a *comparative matrix*, crossing the initial condition assessment values at different scales and applicable renovation actions (to be fulfilled through specific technical solutions). These should be selected according to relevant parameters related to the subjective interests of the involved stakeholders. For instance, in the case of Mediterranean sites, such actions could be grouped and chosen according to the recurrent construction methods and materials. They could be, for example, roof tiles substitution, window replacement, installation of movable partitions, addition of external shading systems, integration of vertical connections or entrances, and many more.

Furthermore, these *renovation actions* should be categorized into four groups, as follows, according to their extent: minor, moderate, significant, and major (Fig. 3). In this way, each initial scale, according to its level of "ductility," could be associated with a renovation action degree. In addition, each action should be then prioritized through specific criteria weighting methods, thus producing a numerical value for each of the slots. The matrix would be then ready to be used for the evaluation of different renovation hypotheses. After the assessment process, the addition of the values of all actions at multiple scales would lead to a numerical result, indicating the feasibility index of the renovation, in terms of flexibility.

The potential of this DST of assessing the existing building performance and producing a feasibility index for the flexibility outcome of its renovations could be foreseen to be implemented as a relevant parameter within the European Digital Building Logbook. The evaluation of the adaptability and resilience—through the aforementioned indexes—and flexibility of buildings has already been stated to be a fundamental part within the repository, as one of its functionalities is the overview of the building performance [18]. This would lead to several benefits: for instance, the understanding of the flexibility level of buildings could increase their market value, on account of their potential future multiple uses and the extension of their useful life span. Overall, not only could the implementation of such information within a widespread digital tool be instrumental to the assessment of the overall performance of individual buildings but, when implemented at a larger scale, it could reveal the preparedness of the urban built environment to cope with the future need for spatial and functional adaptation.

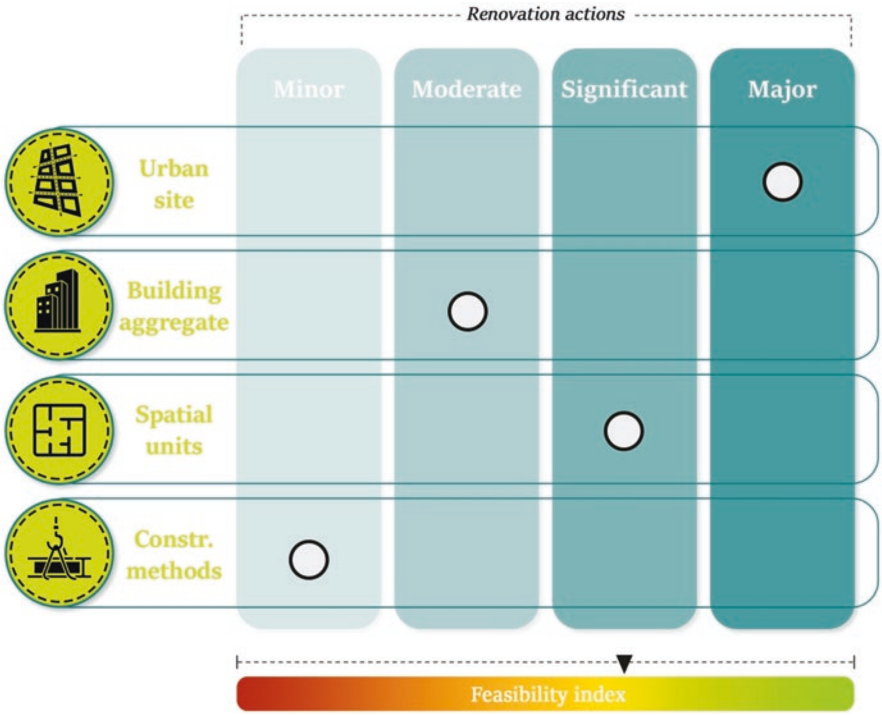

Fig. 3 Schematic representation of the proposed comparative matrix leading to the feasibility evaluation index

5 Conclusion and Future Developments

When looking at future scenarios it is inevitable to consider that spatial, functional, and technological requirements, as well as contextual conditions, are progressively changing more rapidly and are influenced by unpredictable variables, which need to be taken into account in the current design practice. Thus, a resilient urban environment encompasses that the design of new buildings and the forthcoming renovation actions investigate new possibilities for the redefinition of the internal configurations of space, in order to adapt to the different changing uses but also to enhance preparedness against unexpected events.

The Decision Support Tool proposed within the present paper allows for the evaluation of the reversibility of specific objects of intervention toward the achievement of the desired level of performance. In fact, through the analysis conducted with this tool, it seems possible to identify the positioning of the As-Built state with respect to the final objective, therefore intervening with compensation strategies, if necessary, at the different identified application scales, depending for instance on the budget, the type of ownership, and any other specific constraints related to the intervention.

Clearly, a tool of such a kind is well suited to be further developed; the research activity on which its delivery is based indeed has allowed for the definition of the theoretical reference framework, as well as the construction of its methodological scheme. Subsequent development foresees the insertion within the abovementioned matrix of a sample of data and related actions, useful to deepen the analysis. The data can be partly derived from existing evaluation tools for the assessment of the sustainability level, quality and energy efficiency of buildings, such as the LEED rating systems, or by analyzing a large sample of buildings, dividing them, for example, by clusters, according to the characteristics that unite them, trying to identify the recurring traits that can influence the actions connected with their renovation.

Once the parameters—those considered as relevant to each application scale—have been defined, it will be possible to associate them with weighted values that will allow to define the intensity level of intervention needed to reach the desired goal.

References

1. United Nations Environment Programme. (2021). 2021 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector, Nairobi. https://www.unep.org/resources/report/2021-global-status-report-buildings-and-construction
2. International Energy Agency – IEA. (2021). *Tracking buildings 2021*. IEA. https://www.iea.org/reports/tracking-buildings-2021
3. EU Commission. (2020). *Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0562&from=EN
4. EU Commission. (2020). *In focus: Energy efficiency in buildings*, Brussels. https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-lut-17_en#:~:text=Today%2C%20roughly%2075%25%20of%20the,materials%20when%20constructing%20new%20houses
5. EU Commission. (2020). *Communication: A renovation wave for Europe – Greening our buildings, creating jobs, improving lives*, p. 1. https://eur-lex.europa.eu/resource.html?uri=cellar:0638aa1d-0f02-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF. https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf
6. CRESME – Centro Ricerche Economiche, Sociologiche e di Mercato nell'Edilizia. (2021). *Il mercato delle costruzioni 2022. XXXI Rapporto congiunturale e previsionale Cresme. Lo scenario 2021–2026.*
7. EU Commission. (2019). *Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU – Final report*. https://op.europa.eu/en/publication-detail/-/publication/97d6a4ca-5847-11ea-8b81-01aa75ed71a1/language-en/format-PDF/source-119528141
8. Bellomo, M., & Pone, S. (2011). Il retrofit tecnologico degli edifici esistenti: qualità dell'abitare, sostenibilità ambientale, rilancio economico. *Technè, 1*, 82–87. https://oaj.fupress.net/index.php/techne/issue/view/342/37
9. Lavagna, M., Campioli, A., Dalla Valle, A., Giorgi, S., & Caroli, T. (2020). Strategie costruttive e valutazioni ambientali per la temporaneità, circolarità e reversibilità. *Technè, 20*, 157–166. https://oaj.fupress.net/index.php/techne/issue/view/541/160
10. United Nations Framework Convention on Climate Change (UNFCCC). (2015). *The Paris Agreement*. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

11. United Nations Environment Programme. (2019). *Emissions Gap Report 2019*. https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf?sequence=1&isAllowed=y
12. EU Commission. (2019). *The European Green Deal*. https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF
13. Directive 2018/844/EU of the European Parliament and of the Council of 30 May 2018, Official Journal, L.156/75. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=IT
14. EU Commission. (2021). *Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings*, Brussels. https://eur-lex.europa.eu/resource.html?uri=cellar:c51fe6d1-5da2-11ec-9c6c-01aa75ed71a1.0001.02/DOC_1&format=PDF
15. EU Commission. (2020). *Communication: A renovation wave for Europe – Greening our buildings, creating jobs, improving lives*. https://eur-lex.europa.eu/resource.html?uri=cellar:0638aa1d-0f02-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF
16. E3G. (2021). *Renovate2Recover: How transformational are the national recovery plans for buildings renovation?* https://www.renovate-europe.eu/renovate2recover-how-transformational-are-the-national-recovery-plans-for-buildings-renovation/
17. Van Hinte, E., et al. (2003). *Smart architecture*. 010 Publishers.
18. European Commission, Executive Agency for Small and Medium-sized Enterprises, Volt, J., Toth, Z., & Glicker, J. (2020). *Definition of the digital building logbook: Report 1 of the study on the development of a European Union framework for buildings' digital logbook*. Publications Office. https://data.europa.eu/doi/10.2826/480977
19. Dameri, R. P. (2013). Searching for Smart City definition: A comprehensive proposal. *International Journal of Computers & Technology, 11*(5). https://www.researchgate.net/profile/Renata_Dameri/publication/283289962_Searching_for_Smart_City_definition_a_comprehensive_proposal/links/5630cd6608ae2df441bb7e5d.pdf
20. Sinopoli, J. (2010). What is a smart building? In J. Sinopoli (Ed.), *Smart building systems for architects, owners and builders* (pp. 1–5). Elsevier Inc.. https://doi.org/10.1016/B978-1-85617-653-8.00001-6
21. Al Dakheel, J., et al. (2020). Smart buildings features and key performance indicators: A review. *Sustainable Cities and Society*, 61. https://doi.org/10.1016/j.scs.2020.102328
22. EU Commission. (2012). *Communication: The EU approach to resilience: Learning from food security crises*, p. 5. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0586&from=EN
23. World Bank Group. (2015). *Building regulation for resilience: Managing risks for safer cities*. World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/24438
24. World Economic Forum. (2022). *How to build climate resilience into the construction industry.* https://europeansting.com/2022/03/24/how-to-build-climate-resilience-into-the-construction-industry/. Accessed 9 July 2022.
25. International Finance Corporation (IFC). (2021). *Building Resilience Index, User Guide*. https://assets.ctfassets.net/7q5irs6y1cem/4lNBFRA1y0oHZISkRuCCT0/df1a36e14cad6936ed47716fbf70ec98/BRIUserGuide-v1.pdf

Integrating Different PV Roofs on a Heritage Building Considering Aesthetic, Technical, Energy, and Environmental Aspects: A Multi-perspective Approach

Elena Lucchi and Eva Schito

1 Introduction

Energy consumption of existing historic buildings can be reduced significantly using photovoltaic (PV) technologies to favor energy transition, human comfort, and building conservation toward the exploitation of renewable energy sources (RES). Despite these technologies have several benefits related to reliability, modularity, versatility, low maintenance costs, and peak shaving, their application in heritage buildings is hindered by economical, legislative, informative, and aesthetic barriers [1]. International research projects, guidelines, and case studies on PV application provide clear criteria to guarantee their aesthetic, technological, and energy integration [2]. Tailored design is recommending for ensuring heritage-compatibility, also matching aesthetical appeal, multifunctionality, and energy performances [1–4]. The development of innovative PV products favors their integration and compatibility, thanks to customized shapes, vast color ranges, high-resolution printings, and low-reflectivity coatings [2, 3]. Multi-perspective approaches that engages different competences (i.e., architecture, engineering, landscape design, conservation, physics, biology, economics, sociology) are fundamental for considering all the aspects involved in the heritage integration of PV system in architecturally sensitive areas and buildings [2–4].

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2 The Multi-perspective Approach

The research aims at developing a multi-perspective approach for integrating different PV roofs on a heritage building, considering aesthetic, technical, energy, and environmental aspects. To this purpose, a methodology using qualitative and quantitative evaluations has been implemented. Qualitative evaluation concerns the selection of heritage-compatible PV interventions through the support of focus groups with the local Heritage Authority (HA) to ensure aesthetic and technical integration. Quantitative evaluation is based on dynamic Building Energy Simulation (BES) for identifying integrated PV solutions with the building-energy system and reducing nonrenewable primary energy uses or CO_2 emissions (Fig. 1). This approach is applied to the Rustico Macchi, a heritage building located in Morazzone (Province of Varese, Italy), and owned by the Fondo per l'Ambiente Italiano (FAI). The Rustico Macchi is a part of a heritage complex composed also by a Villa, and a wide garden. The Villa is a 17th Century building with a typical neoclassical style based on a L-shape and finely decorated. The building was completely restored in 2020-21 for hosting a house-museum. The Rustico is an unused nineteenth-century rural building that needs a complete renovation to host scholastic activities and exhibitions related to its agricultural background. Few years ago, a regenerative design project started to safeguard its traditional morphology, typology, materials, and constructive technologies, also converting solar energy into electrical energy.

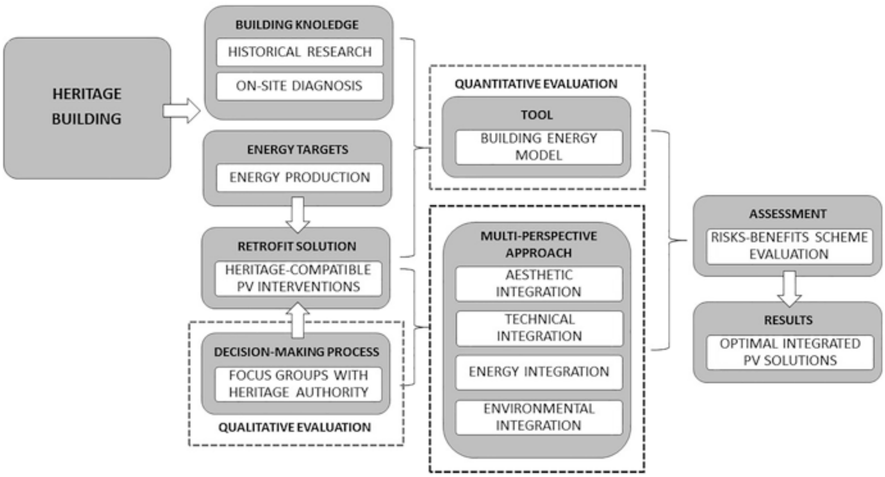

Fig. 1 The research methodology (source: Authors' elaboration)

3 Case Study: Rustico Macchi

Rustico Macchi (Fig. 2) has a volume of about 470 m^3 and a floor area of about 150 m^2. Typical materials (as stone and bricks) are used for the external opaque walls (thickness: 0.5–0.6 m, thermal transmittance: ~1 W/m^2K). Single-glass windows with wooden frames are present (thermal transmittance: ~5 W/m^2K). The building faces south and it is adjacent to other buildings with heating and cooling systems. Heating requirements (through a hybrid heat pump) and cooling services (through a chiller) are present, together with electrical energy requests for lighting and other appliances. Other details of the case study are presented in [8].

3.1 Focus Groups with Heritage Authority

Heritage-compatible PV technologies with the Rustico Macchi have been discussed in two focus groups with the local HA. Two different PV approaches are analyzed: (i) Building Attached Photovoltaic (BAPV) based on the application of PV modules on the building element to produce electricity; (ii) Building Integrated Photovoltaics (BIPV) based on the integration of multifunctional PV systems to provide both energy and building functions (i.e., mechanical resistance, fire, weather thermal or

Fig. 2 The Rustico Macchi in Morazzone (Italy). (Source © FAI – Fondo Ambiente Italiano, 2018): (**a**) the building and its surroundings; (**b**) schematic façade of the building; (**c**) plan of the roof

acoustic protection, daylight, and security control). Conventional (i.e., crystalline silicon cells) and innovative (i.e., colored, thin films) PV system are discussed, considering aesthetic and technical integration. Aesthetic integration implies a compatible visual, spatial, and material interaction between PV and traditional technologies. Main criteria consider visual impact minimization, safeguard of original geometries, features, proportions, colors, texture, patterns, and reduction of material losses and changes. Technical integration deals with the reduction of the risks connected to PV installation, durability, reversibility, and design of the intervention. A synthesis of HA recommendations is reported in Table 1.

3.2 Building Energy Simulation

To analyze the energy and environmental integration of PV system, a model of the building-HVAC system has been created in TRNSYS (envelope) [5] and MATLAB (heating and cooling system) [6]. Using a typical climate year data [7], profiles of visitors' presence in the building opening hours, internal gains due to electrical appliances, and the characteristics of opaque and glazed elements, the heating (Q_{heating}) and cooling (Q_{cooling}) hourly requirements have been provided [8]. These requests have been used to estimate the energy input at the generators (i.e., heat pump and natural gas boiler in the heating season, chiller in the cooling season). In heating season, a switch temperature of 5 °C has been chosen as the lowest external temperature when the heat pump can operate, otherwise the boiler is used. The electrical energy needed for indoor appliances (E_{OU}) and for the reversible heat pump in both seasons can be delivered by the grid or by PVs. The PV system can also send electrical energy to the grid, if higher than that requested by the building. Among all PV technologies (Table 1), a selection of 5 PV scenarios (1÷5) has been chosen by the owner for further analysis, corresponding to the types that can be installed on the roof. A scheme of the system is represented in Fig. 3. The characteristics of those PV solutions are shown in Table 2.

The indicators chosen for the energy and environmental analysis of PV integration are:

- Savings of input nonrenewable primary energy, $\text{SavPrEn}_{\text{in}}$, compared to No-PV solution, to be evaluated as:

$$\text{SavPrEn}_{\text{in}} = \frac{\sum_{i=1}^{8760}\left(f_{nr,gas}\times E_{gas} + f_{nr,el}\times E_{el,\text{b}}\right)_{\text{NoPV}} - \sum_{i=1}^{8760}\left(f_{nr,gas}\times E_{gas} + f_{nr,el}\times E_{el,\text{b}}\right)}{\sum_{i=1}^{8760}\left(f_{nr,gas}\times E_{gas} + f_{nr,el}\times E_{el,\text{b}}\right)_{\text{NoPV}}}\times 100 \quad (1)$$

Table 1 Selection of the PV interventions according to the focus groups with local HA

Building element		PV type	PV technology	%	HA recommendations		N. Scen.
Roof	Building roof	No PV	–	–	Rural function and low conservation level favor the heritage-compatibility with PV technologies	✔	1
		BAPV	Polycrystalline	50	BAPV approach is heritage-compatible, but conventional PV have a different aesthetical appearance of traditional materials. The partial roof coverage permits to conserve original tiles	✖	–
				100	BAPV approach is heritage-compatible, but conventional PV have a different aesthetical appearance of traditional materials	✖	–
		BIPV	Polycrystalline	50	Not allowed on the building	✖	–
				100		✖	–
			PV tile	100	Allowed in the building for the low conservation level of the roof, selecting terracotta PV cells	⚠	2
			Hidden colored (terracotta)	50	Allowed on the building, selecting dimensions, colors, and shapes compatible with original roofs. The partial roof coverage permits to conserve original tiles, putting attention to the detailed design	⚠	3
				100	Allowed on the building, selecting dimensions, colors, and shapes compatible with original roofs	⚠	4
	Cantilevered roof	BIPV	Thin film	100	Allowed for replacing metal roofs	⚠	5

(continued)

Table 1 (continued)

Building element		PV type	PV technology	%	HA recommendations		N. Scen.
Façade	External façade	BAPV	Hidden colored (gray)	100	Not allowed on the building	✖	–
	Internal façade			100		✖	–
	Balcony	BAPV	Hidden colored (gray)	100	Allowed for the low conservation level of the building, selecting dimensions, colors, and shapes compatible with original roofs	▲	6
		BIPV		100	Not allowed on the building	✖	–
	Stairwell o lift	BIPV	Semitransparent	100	Heritage-compatibility is favored because stairwell is a new element. It is important to select shape, dimensions, colors, reflectance compatible with original technologies	▲	7
			Hidden colored (gray)	100	They are new elements, thus this favor heritage-compatibility. It is important the selection of shape, dimensions, colors, reflectance compatible with traditional building technologies	▲	8
	Greenhouse	BIPV	Semitransparent	100	Allowed on original balcony, selecting original patterns and high transparency	▲	9

Source: Authors' elaboration
✓ = Recommended, ▲ = To be specifically evaluated, ✖ = Not recommended

- Savings of CO_2 emissions due to the energy input, SavProd_{CO_2}, compared to No-PV solution, to be evaluated as:

$$\text{SavProd}_{CO_2} = \frac{\sum_{i=1}^{8760}\left(f_{em,gas} \times E_{gas} + f_{em,el} \times E_{el,\text{b}}\right)_{\text{NoPV}} - \sum_{i=1}^{8760}\left(f_{em,gas} \times E_{gas} + f_{em,el} \times E_{el,\text{b}}\right)}{\sum_{i=1}^{8760}\left(f_{em,gas} \times E_{gas} + f_{em,el} \times E_{el,\text{b}}\right)_{\text{NoPV}}} \times 100 \quad (2)$$

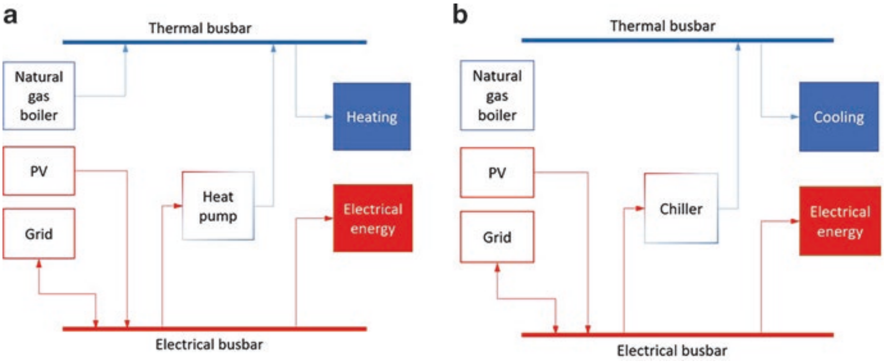

Fig. 3 Scheme of the simulated system: (**a**) heating season, (**b**) cooling season (source Authors' elaboration)

Table 2 Main characteristics of the simulated PV scenarios

Simulated scenario	Slope [°]	Azimuth [°]	Effective area [m²]	Reference efficiency [–]
1	–	–	–	–
2	27	0	16.3	0.153
3	27	0	97.5	0.136
4	27	0 and 270	97.5 (az = 0°) 10 (az = 270°)	0.136
5	0	–	15.6	0.146

Source: Authors' elaboration

The equations to be used for the estimation of the input energy of natural gas and grid electricity and for the electrical energy production at PV are the following:

$$E_{\text{gas}} = Q_{\text{heating,boiler}} \times \frac{1}{\eta_{\text{e}}\eta_{\text{c}}\eta_{\text{d}}\eta_{\text{boiler}}} \tag{3}$$

$$E_{\text{el,b}} = \max\left[0, Q_{\text{heating,HP}} \times \frac{1}{\eta_{\text{e}}\eta_{\text{c}}\eta_{\text{d}}\text{COP}} + Q_{\text{cooling}} \times \frac{1}{\eta_{\text{e}}\eta_{\text{c}}\eta_{\text{d}}\text{EER}} + E_{\text{OU}} - E_{\text{PV}}\right] \tag{4}$$

$$E_{\text{PV}} = \eta_{\text{PV}}\eta_{\text{INV}}S_{\text{PV}}I_{\text{sol}} \tag{5}$$

The conversion factors used in Eqs. 1 and 2 are reported in Table 3 [9, 10]. Further details on the model and parameters used for the energy estimation can be found in [8].

Table 3 Nonrenewable primary energy and CO_2 emissions conversion factors for natural gas and grid electricity

	Conversion factor	Value
Nonrenewable primary energy	Gas ($f_{nr, gas}$)	1.05 [−]
	Electrical energy ($f_{nr, el}$)	1.95 [−]
CO_2 emissions	Gas ($f_{em, gas}$)	202.4 [g/kWh]
	Electrical energy ($f_{em, el}$)	289.9 [g/kWh]

Source: Authors' elaboration

4 Risk-Benefit Assessment

4.1 Assessment of the Indicators

A comparative assessment of different PV scenarios in the heritage building is realized according to the risk-benefit scheme elaborated in International Energy Agency (IEA) Task 59 [4] (Table 4). Aesthetic evaluation shows the visual impact of PV tiles for difference in colors, patterns, and reflectance with original tiles. Otherwise, hidden colored PV panels are visual and spatial compatible with the building. The material impact is lower for partial roof coverage rather than total coverage. PV films are material and spatial compatible, with a low visual impact thanks to their aesthetical appearance similar to traditional roofs. Technical evaluation shows the points of attention in design and construction phases of the different PV scenarios regarding hygrothermal, structural, reversibility, energy efficiency, and fire safety risks. Considering the energy and environmental integration, the values of $SavPrEn_{in}$ highlight that all PV scenarios allow a reduction of nonrenewable amount of energy higher than 20%, compared to reference no-PV scenario. In addition, values higher than 1.00 are found for nonrenewable primary energy ratio (PER), defined as the ratio between the final energy uses and the nonrenewable primary energy input. The higher this value, the higher is the share of renewable primary energy used for the electrical loads. Finally, hidden-colored PV (scenarios 3–4) allows a higher reduction of CO_2 emissions (over 30%), compared to no-PV solutions. Due to the lower electrical energy production, scenarios 2 and 5 perform suboptimally (reduction of CO_2 emissions around 20%).

4.2 Discussion

Table 5 shows the comprehensive assessment for the scenarios in analysis. Scenario 1, without PV interventions, is aesthetic and technical heritage-compatible, but not energy and environmental integrated. On the contrary, other PV scenarios perform better from an energy and environmental point of view, with different levels of integration. To rank the results in terms of energy and environmental indices, a

Table 4 Multi-perspective approach for the evaluation of different PV roofs

Assessment criteria	Scenario 1	2	3	4	5
Aesthetic integration					
Risk of material impact	Absence of material impact or material losses on the heritage building	High material impact due to loss of original materials for PV tiles application	Low material impact due to the low conservation level, to the reversibility of the fixing systems, and to the possibility of partially conserving original tiles	Low material impact due to the low conservation level, and to the reversibility of the fixing systems	Absence of material impact or material losses on the heritage building
Risks of visual impact	Absence of visual impact	Visual impact due to the contrast between original and PV and tiles in color, reflectance, and pattern	Visual compatibility based on coplanarity, color match, reflectance control, frameless system		Low visual compatibility based on color match, reflectance control, frameless, and lightness
Risk of spatial impact	Absence of spatial impact	Absence of changes in the geometrical relationships between the building and the surroundings			
Technical integration					
Hygrothermal risk and waterproof	No changes in the hygrothermal profile	Verify the potential condensation risks between PV tiles and original roof	Verify the potential condensation risks in the junction between PV e original tiles.	Absence of condensation risks for plastic encapsulation, and ventilation around the panels	Absence of hygrothermal risk for the new roof installation
Structural risk	No changes in the structural behavior	Absence of structural risk for PV lightweight	Verify the potential structural risks due to PV weight		Absence of structural risk for PV lightweight
Reversibility	Not applicable for the absence of PV system	Irreversible system	Reversibility thanks to the use of reversible fixing systems and the low conservation level		New PV roof installation
Reduction efficiency risk		Control the risk for efficiency reduction	Ventilation reduced the risk for efficiency reduction		Absence of risk for efficiency reduction
Fire safety		Product tested according to international standard, but fire prevention regulations must be considered in design and construction phases			
Design and installation		Detailed design and accurate installation are needed	Detailed design and accurate installation of the junction between roof and PV modules are needed	Detailed design and accurate installation of the roof are needed for the complexity of the roof shape	Detailed design and accurate installation are needed
Energy integration					
$SavPrEn_{in}$ [%]	0	23	36	36	21
$nr-PER$ [-]	0.80	1.04	1.24	1.25	1.01
Environmental integration					
$SavProd_{CO_2}$ [%]	0	21	32	33	19

Source: Authors' elaboration
■ = No risks, ■ = Low risk, ■ = High risk

threshold level of 25% has been set to distinguish a higher or lower integration (25% is set as objective for emission reduction in typical Baseline Emission Inventories [11]). Solution 2 is not heritage-compatible from aesthetical and technical points of

Table 5 Risk-benefit scheme assessment of different PV scenarios

Type of integration	Scenario 1	2	3	4	5
Aesthetic	🟩	🟨	🟨	🟨	🟨
Technical	🟩	🟨	🟨	🟨	🟨
Energetic	🟥	🟨	🟩	🟩	🟨
Environmental	🟥	🟨	🟩	🟩	🟨

🟩 = Suggested, 🟨 = Acceptable, 🟥 = Not suggested
Source: Authors' elaboration

view, due to the high visual impact of PV tiles and to the irreversibility of the fixing systems. The visual impact is related to difference in colors, patterns, and reflectance between traditional and PV tiles that visually affect the historic character of the building [4]. Also, fixing systems and PV tiles are irreversible; thus, the intervention cannot be undone without damage to the building [4]. Solutions 3 and 4 (which are hidden terracotta-colored PV modules) are the ones with the highest level of integration on all the four categories, showing low aesthetical risks as well as a reduction of nonrenewable primary energy and CO_2 emissions higher than 30%. At the same time, the use of these technologies on BIPVs allows an acceptable technical integration, which requires a careful risk assessment during design and installation phases. Also, their aesthetic aspect should be discussed in advance with local HA, for reducing their potential negative aesthetic and visual impacts. This favors the concealment of PV panels, connections, pipes, mechanical equipment, electrical and plumbing conduit, fixing elements, frames, and mounting systems from public spaces. Moreover, color should fit original finish of the building, surroundings, and established roof materials and reflectance should be minimized, selecting matte finish for exposed modules, hardware, frames, and piping. Finally, solution 5 guarantees the absence of material and spatial impact as well as of technical risks. A detailed design is necessary to control the visual impact due to limited color range and high reflectance of the panels. Energy and environmental aspects are similar to solution 2. Considering all the levels of integrations, all the PV solutions require a tailored design due to the aesthetic and technical risks for safeguarding heritage materials and values, even if their energy and environmental integration is suggested.

5 Conclusion

In this research, the possibility of installing innovative BIPV systems on heritage buildings is analyzed, through an approach that considers four levels of integration (i.e., aesthetic, technical, energetic, and environmental integration). Through tailored design, the reduction of energy and environmental emissions is possible, ensuring an aesthetic and technical integration. That result represents a great opportunity to fit European climate targets scheduled for the next years, while preserving the building heritage of historical value. This approach has been shown through a case study, an Italian heritage building, where the current scenario (no-PV solution) has been compared to four scenarios including PVs on the roof. Among the solutions, hidden terracotta-colored BIPV panels have been identified as the suggested ones, allowing a reduction of 30% of nonrenewable primary energy and emissions and guaranteeing the aesthetic and technical compatibility. Future development of this study will include an optimized design of the HVAC system of the building, and the integration of economic aspects as a follow-up of the integrated approach.

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References

1. Lucchi, E. (2022). Integration between photovoltaic systems and cultural heritage: a socio-technical comparison of international policies, design criteria, applications, and innovation developments. *Energy Policy, 171*, 113303.
2. Lucchi, E., Baiani, S., & Altamura, P. (2023). Design criteria for the integration of active solar technologies in the historic built environment: Taxonomy of international recommendations. *Energy and Buildings, 278*, 112651.
3. Lucchi, E., Adami, J., Peluchetti, A., & Mahecha Zambrano, J. C. (2023). Photovoltaic potential estimation of natural and architectural sensitive land areas to balance heritage protection and energy production. *Energy and Buildings, 290*, 113107.
4. Polo López, C. S., et al. (2021). Risk-benefit assessment scheme for renewable solar solutions in traditional and historic buildings. *Sustainability, 13*, 5246.
5. Klein, S. A. (2016). *TRNSYS 17: A transient system simulation program*. Solar Energy Laboratory: University of Wisconsin. http://sel.me.wisc.edu/trnsys
6. MATLAB, version R2021a. (2021). The MathWorks Inc.
7. CTI (Italian Thermotecnical Committee). (2012). *Italian typical meteorological years.*https://www.cti2000.it/index.php?controller=news & action=show & newsid=34985 Accessed 01/04/2022.
8. Lucchi, E., & Schito, E. (2023). Challenges and opportunities for the integration of photovoltaic modules in heritage buildings through dynamic building energy simulations. In: Furferi, R., Governi, L., Volpe, Y., Gherardini, F., Seymour, K. (eds). The Future of Heritage Science and Technologies. Florence Heri-Tech 2022. Lecture Notes in Mechanical Engineering. Springer, Cham.
9. Decreto Interministeriale 26 giugno 2015 – Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici. Gazzetta Ufficiale della Repubblica Italiana. (2015).
10. ISPRA, Rapporto 317/2020, “Fattori di emissione atmosferica di gas a effetto serra nel settore elettrico nazionale e nei principali Paesi Europei”.
11. Croci, E., et al. (2021). Low carbon urban strategies: An investigation of 124 European cities. *Urban Climate, 40*, 101022.

Experimental Tests for the Adaptation of a Curtain Wall Subjected to Extreme Events in the Mediterranean Area

Evelyn Grillo, Martino Milardi, and Francesca Olivieri

1 Introduction

For several years now, the effects of climate change illustrate a complex scenario due to the consequences of climate anomalies affecting and altering different “sectors” of human activities, such as the economy, security and health, and the built environment. Accurate scientific studies described in the Sixth Assessment Report (AR6) of IPCC Working Group 1, “*Climate Change 2021. The Physical Science Basis”* [1] estimate the possibility of exceeding the global warming level of 1.5 °C in the coming decades, of which human activities are responsible for about 1.1 °C heating compared to the pre-industrial period 1850–1900. Furthermore, there are mechanisms, called *feedback*, that can amplify or diminish the effects of a climate forcing. The forcing factor is the increase in CO_2 concentration, which alters the earth’s energy balance and causes an increase in temperature: feedback that increases the initial warming is “positive feedback” while feedback that decreases the initial warming is called “negative feedback” [2]. To substantiate this scenario, the “*Global Status Report 2021”* [3] indicates that the global share of CO_2 emissions related to energy consumption from buildings and construction compared to other sectors will be 37% in 2020. Therefore, the construction sector is directly involved in this process and is called upon to define new procedures, application methods, and

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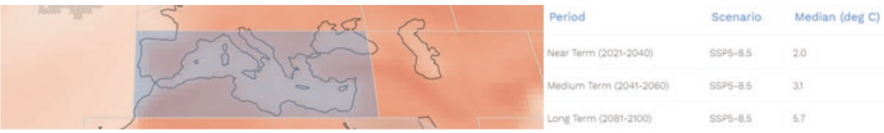
innovative technological solutions in line with the climate and energy targets promoted by the *European Green Deal* [4] and aimed at impact mitigation and adaptation. Although the renewed need for environmental quality is now a categorical imperative, this implies the dissemination of projects incorporating climate change mitigation already at the design stage [5] to innovate the construction sector toward more effective strategies and innovative processes for reducing impacts.

Specifically, in the Mediterranean Basin [6], high-temperature events, such as heatwaves and heat islands, variations in the precipitation regime, such as water bombs and floods, and tropical cyclones known as "Medcane" (Mediterranean Hurricanes) [7] will probably become more frequent and/or more extreme. Figure 1 shows future projections of maximum temperature in the Mediterranean context analyzed through climate models in the RCP 8.5 scenario. For the three time periods 2021–2040, 2041–2060, and 2081–2100, the temperature will increase by 2 °C, 3.1 °C, and 5.7 °C, respectively, highlighting the need for a radical change.

As shown in Fig. 2, future rainfall projections in the Mediterranean area in the RCP 8.5 scenario referring to periods 2021–2040, 2041–2060, and 2081–2100 show a decrease in precipitation by 27.1%, 45.7%, and 83.2%, respectively. Thus, while the overall amount of precipitation will decrease in the Mediterranean, extreme storms will prevail in the northern area, and flash floods are and will probably remain the most dangerous weather hazards affecting Mediterranean Countries.

These climatic variations can be a critical point for the building envelope, especially to the effects induced on the glazing elements that make up the curtain wall systems. Although most of today's curtain wall systems are technologically advanced, recent studies specify that the continuous impact of environmental conditions causes a significant loss of performance (up to 54% due to air infiltration, 18.53% due to wind pressure) during the life of the curtain wall system [8]. Furthermore, thermal stresses negatively affect the façade materials, leading to heat losses through aluminum or steel mullions and transoms [9]. To solve these problems, it is necessary to develop new components that achieve a high degree of



Period	Scenario	Median (deg C)
Near Term (2021-2040)	SSP5-8.5	2.0
Medium Term (2041-2060)	SSP5-8.5	3.1
Long Term (2081-2100)	SSP5-8.5	5.7

Fig. 1 Maximum temperature in Mediterranean Area in RCP scenario 8.5. (Source: https://interactive-atlas.ipcc.ch/)

Period	Scenario	Median (%)
Near Term (2021-2040)	SSP5-8.5	-27.1
Medium Term (2041-2060)	SSP5-8.5	-45.7
Long Term (2081-2100)	SSP5-8.5	-83.2

Fig. 2 Precipitation in the Mediterranean area in the RCP 8.5 scenario. (Source: https://interactive-atlas.ipcc.ch/)

adaptation and flexibility for different external stresses. Adaptive topics require the potential and enablement of innovative technologies from different fields, such as architecture, thermodynamics, and materials engineering [10]. The reasons behind the adoption of "*Adaptive Façades*" [11] lie in their ability to change their functions, characteristics, or behavior over time in response to transient performance requirements and boundary conditions, intending to improve the overall performance of the building envelope [12].

In this scenario, the contribution refers to an in-progress experimental research, with the ultimate aim to address an operational methodology capable of orienting interventions in the built environment toward adaptive strategies, with contributions from technological innovation. The research is within the "*Sustainable Construction*" Trajectory of the Smart Specialisation Strategy (S3) Calabria and it is in line with the "*Climate Change, Mitigation and Adaptation*" innovation field of Cluster 5 of the PNR 21-27. The research's objective is to analyze the possibility of innovation in the field of adaptive façades through the definition and the development of a new adaptive model that can be applied to curtain wall systems. The adaptive module is intended to adapt in a reversible and controllable manner to extreme temperatures and precipitation for future climate scenarios in the Mediterranean area. The research work is structured according to sequential steps: moving from a study and analysis phase to the application phase of implementation and subsequent testing of the adaptive model through testing activities at the TCLab Section of the Building Future Lab (BFL) of the Mediterranean University of Reggio Calabria. It is important to underline that the lab is one of the 40 partners of the five-year innovation project called *Metabuilding Labs*, financed by the EU Horizon 2020 and to create easy access to a network of high-value test facilities that enable them to develop and test innovative envelope solutions for next-generation buildings.

In this paper, the authors present the first part of the testing activities conducted on a curtain wall Mock-Up, without the adaptive model, to verify its performance and technological characteristics in relation to air permeability and water-tightness, according to American testing standards.

2 Aims and Objective

The objective of this research is to improve the performance of curtain walls in the face of the impacts of extreme climatic events through the development of an adaptive model—the result of research—capable of reacting dynamically to specific climatic conditions. Because factors such as curtain wall performance and climatic conditions vary, measurable control is required to support the "building-context relationship" through new ways of analyzing the effects of extreme events on buildings and, where possible, verifying the outcomes of their bi-univocal relationship.

Facades are considered one of the most fragile and vulnerable components of buildings because of glass's relatively low tensile strength and mostly fragile behavior, compared to other traditional materials [13]. Regardless of how a curtain wall is designed, it is not possible to avoid the unwanted transfer of heat, mass, and moisture between the internal and external environment, particularly due to the delta of temperature and humidity in most periods of the year. Temperature changes that create the so-called "thermal movement" can negatively affect the facade elements, for example, causing the expansion and contraction of the materials. For these reasons, it becomes useful to relate the technical performance and "environmental behavior" of curtain walls and to highlight their potential limits in relation to the effects of climate change (thermal shocks, water bombs, wind loads) and to verify how they can trigger and aggravate climatic phenomena. This process includes heat conduction and radiation exchange from envelope surfaces and also direct air exchange through ventilation and leakage [14].

As users' well-being needs evolve, the notion of changing façade configuration seems to be a new approach to improve thermal and visual comfort [15]. However, there are difficulties in designing adaptive systems and components, as the technologies currently on the market are scarcely applicable or only used in buildings with a particular intended use or of size or value that justifies the adoption and thus the cost of such systems [16]. The reasons for the limited use of adaptive building envelopes in buildings at the design stage include the lack of concrete evidence of the benefits of the technology, together with the lack of benchmarks, standards, and test procedures for their performance evaluation [17], performance that cannot be sufficiently characterized by static performance indicators (U-value, g-value, T-vis, etc.) [18]. In this perspective, Mock-Up tests play a key role as they are crucial to assess the adaptability of untested systems and to contribute to later finalized projects. For example, water-tightness tests attempt to reproduce extreme conditions to determine the resistance to the passage of water through a façade. Against this, investigations and analyses on the behavior of curtain walls in climate change situations could guide the configuration of new adaptive scenarios for this type of system, directing design decisions toward the optimal and calibrated option to the different contexts of reference and relationship. Following the illustrated scenario, the experimental research is aimed at:

- Elaboration of performance repertoires to guide the design of components with adaptive criteria and reasoned investigation of innovative materials for extreme climatic conditions.
- Identification of the current performance (without the adaptive model) of the curtain wall system with mullions and transoms, chosen for experimentation, through the conduction of laboratory tests, thanks to the TCLab Section of the BFL, relating to air permeability and water-tightness under static and dynamic conditions.
- Definition, through a synthesis framework, of the performance to be improved for the adaptive behavior of the façade system, to the increase in temperature and precipitation to guide the choice of the most appropriate material for the development of the adaptive model.
- Instruction and construction of feasibility tests useful for the development of the prototype to be started for experimentation and testing activities.

- Design experimentation through simulation and verification of the adaptive behavior of the model applied on a curtain wall Mock-Up.
- Comparison of the results obtained to air permeability and water-tightness tests under static and dynamic conditions on the curtain wall Mock-Up without and with the adaptive model.

3 Methodological Structure

In relation to the abovementioned aims, the research and its activities are organized in theoretical-operational phases: from the identification of environmental problems in the Mediterranean area, to the study of advanced technologies and materials for the adaptive management of curtain walls, to arrive at an idea of an adaptive model and the verification of its technical feasibility on a curtain wall, through laboratory experimentation activities. The general objective of studies is to identify some critical nodes between buildings and their contexts. The difficulty seems to be the evaluation of the stresses of climatic phenomena affecting building envelopes, calling for the need to verify the technical feasibility of interventions, oriented and supported by experimentation and validation of the results obtained. Specifically, from a methodological point of view, the following sequential phases are reported:

- *State-of-the-art investigation phase*: The first phase of the research study concerns the investigation of the state of the art, of the European and national regulatory framework, regarding climate change and, therefore, the identification of the open problems that characterize it. In particular, the activity's objective is to frame the environmental and energy problems that are today accentuated by climate change and to highlight their impacts to direct adaptation actions on the built environment. From the identification of Mediterranean climate data, attention is focused on some key assumptions based on the need for a renewed building design that responds to the pressing demands for new quality, with respect to extreme events such as the increase in temperature and precipitation in a specific Mediterranean context.
- *Critical-analysis phase*: The second phase relates to the critical analysis of innovative adaptive system, components and materials to highlight their potential, the problematic aspects and to solve the criticalities emerged from the conception of the new adaptive curtain wall system model. It highlights how the adaptive envelope type plays a key role in the control of energy flows between the external and the internal confined environment. The critical investigations on the adaptive modalities of building envelopes, conducted in recent years, aim to define a synthetic framework of the possible configurations that an envelope can assume automatically, achieving comfort conditions and reducing impacts on the built environment. The information regarding the study of materials for extreme climatic conditions made it possible to consider applying an intelligent material with shape memory capability for the experimental phase. Following the sequen-

tial steps, the focus shifts to analyzing the performance of curtain walls to extreme events, identifying possible deficits that may compromise the overall functioning of the envelope. It should be noted that studies and industry regulations prescribe that curtain walls must be air- and watertight, prevent the formation of condensation on internal surfaces, and resist wind load and other external forces acting on the building envelope. Therefore, dynamic evaluation and simulation become essential activities to minimize the risk of unwanted and costly problems during the expected life of a building [19].
- *Experimentation phase*: The third experimentation phase starts at TCLab Section [20], with the possibility of simulating climatic conditions in an urban environment and their effects and testing the adaptability levels of the model applied on a curtain wall system. For experimental use, a representative curtain wall Mock-Up is provided by a partner company of the laboratory. The objective is the study of the curtain wall behavior (Mock-Up on a scale of 1:1) in two steps (without and with the adaptive model) in climate change conditions to identify and configure new adaptive scenarios for a specific environmental context.
- *Verification and validation phase of the results obtained*: The fourth phase of the research concerns the comparison of the results obtained from laboratory tests on the curtain wall system, without and with the adaptive model. The objective of this phase is the elaboration and updating of procedural protocols for the tests, both for subsequent experimental activities and for certification in the regulatory field.

The following section describes the testing methodology for the experimental activities regarding climate change phenomena in the Mediterranean Area.

4 Test Procedure on the Curtain Wall

In the different scientific implications, the instrumental and applicative opportunity of research provides the design process with a new ability to control performance dynamics. These activities are possible thanks to the equipment and machinery of the TCLab laboratory Section. Specifically, the Test Lab consists of a steel framed structure measuring 18 m (15 effective) × 12 m × 4.5 m, closed on three sides while the fourth side is open and flexible to allow for the assembly of 1:1 scale Mock-Up of curtain walls (defined by EN 13830:2015—Curtain Walling), or similar elements, to be tested according to standardized test procedures. The Test Lab consists of an AAV system (air, water, and wind, pressure/depressure), a thermal chamber (dimensions 7 × 5 × 1.50 m), seismic and mobile beams, for the performance of displacement tests and for elastic balances.

The first step of the experimental activities is carried out on a curtain wall Mock-Up without the adaptive model, with the aim to verify its functioning and performance behavior, in relation to the temperature rise phenomena causing heat waves and pluvial flooding. This activity is necessary to guide the technological solutions for the development of the adaptive model.

The curtain wall Mock-Up 6025 × 8820 mm (Fig. 3) consists of an aluminum mullion and transom frame (stick wall system) containing n° 2 opening units (upper projecting, lower tilt-and-turn) and it is made by Aluk Group. The module types are: n° 20 fixed glazing units of 1195 × 1335 mm, n° 8 fixed glazing units of 1195 × 1700 mm, n° 1 top-hung openable element of 1195 × 1700 mm (leaf 1122 × 1627: window A), and n° 1 tilt-and-turn openable element of 1195 × 1700 mm (leaf 1103 × 1608: window B).

In accordance with the test protocols, the following test methods are planned and carried out to evaluate the curtain wall performance concerning the extreme events of heatwaves and pluvial flooding in the Mediterranean Area:

- *Heatwaves*: Air permeability in accordance to ASTM E 283-04 (2012). The test is divided into three different phases: measurement of the air permeability of the test chamber, measurement of the permeability of fixed sample and test chamber joints, and measurement of the overall of the sample and test chamber.
- *Pluvial flooding*: The test consists of applying a constant, uniform amount of water to the external surface of the Mock-Up and the simultaneous application of static and dynamic pressure, in accordance to water-tightness performance under

Fig. 3 Mock-Up of curtain wall subjected to experimental activities. (Credit: TCLab)

static pressure in accordance with ASTM E 331-00 (2009) and water-tightness performance under dynamic conditions in accordance with AAMA 501.1-05-00 (2007).

From the experiments performed, the construction of a performance data framework highlights the potential, criticalities, and malfunctions of the analyzed Mock-Up.

5 Results and Discussion

To provide a more accurate measure of curtain wall performance, the results are processed using data from the system software and test management "Wizard." Results for each individual test are reported in this section.

5.1 Air Permeability Test

The test consists of measuring the air permeability of the Mock-Up, subjected to positive/negative differential pressures of 6.24 lbf/ft^2 (299 Pascal). The environmental parameters of the laboratory during this test are: temperature 11 °C, relative humidity 30.1%, and atmospheric pressure 100.1 kPa. The performance requirements are as follows: for fixed parts, air infiltrations less than 0.06 CFM (ft^3/min, cubic feet per minute); for opening elements, air infiltrations less than 0.10 CFM (ft^3/min, cubic feet per minute). As shown in Table 1, the Mock-Up is subjected to positive/negative differential pressures (6.24 lbf/ft^2, 299 Pascal) and exceeded regulatory limits. Therefore, the Mock-Up has good airtightness, considering the large area of the glazing and that leaks usually occur in the connections between the structural frame and the glazed area. Despite this, it is highlighted that for this type of mullion and transom curtain wall, a slight wind pressure (negative feedback) on the façade can change the system behavior. Unexpected fluctuations in air

Table 1 Air permeability test results at positive and negative pressure

	Positive pressure	*Air permeability*		
	Pa – lbf/ft^2	m^3/h	CFM	CFM × ft^2
Façade	299 – 6.24	4100	2413	0.004
Window A	299 – 6.24	2080	1224	0.056
Window B	299 – 6.24	2950	1736	0.079
	Negative pressure	*Air permeability*		
	Pa – lbf/ft^2	m^3/h	CFM	CFM × ft^2
Façade	299 – 6.24	5020	2954	0.005
Window A	299 – 6.24	3890	2289	0.104
Window B	299 – 6.24	2360	1389	0.064

infiltration during the tests can also be attributed to strong daily winds during the test days and the 10% measurement tolerance of the devices used.

5.2 Water-tightness Performance Under Static Pressure

The test consists of applying a constant and uniform amount of water to the external surface of the Mock-Up and the simultaneous application of a positive test pressure in order to register any water infiltration. The environmental parameters of the laboratory during this test are: temperature 11.8 °C, relative humidity 30.7%, and atmospheric pressure 99.8 kPa. The water supply is performed at a static pressure of 12 lbf/ft^2 (pounds per square foot), 575 Pa for a time of 15 minutes. The amount of water, set at a total of 5 US gallons per square foot in an hour (= 3.4 l/min m^2), is sprinkled with the watering device consisting of a square mesh network of nozzles positioned on a horizontal plane parallel to the plane of the Mock-Up. The test is proceeded successfully up to a pressure of 12psf (positive feedback). The Mock-Up is further subjected to an increase in pressure to verify its limit condition, up to 25.06 psf (1200 Pa), highlighting water infiltration at some points that could compromise the functionality of the entire system (negative feedback) (Fig. 4). Water bypassing façade drainage elements causes failure and deterioration of silicone and sealants. The amount of water infiltrated inside the Mock-Up is measured during static boundary conditions. It has been established that the amount of infiltrated water does not show a correlation with the pressure differential in the system, which indicates that the force causing the infiltration of water is the hydrostatic pressure applied by the water in the sprinkler network. It can be stated that the infiltration level has become stationary very quickly, but these tests show that the condensation/ water channels must be well designed in accordance with the annual rainfall intensity of the reference context.

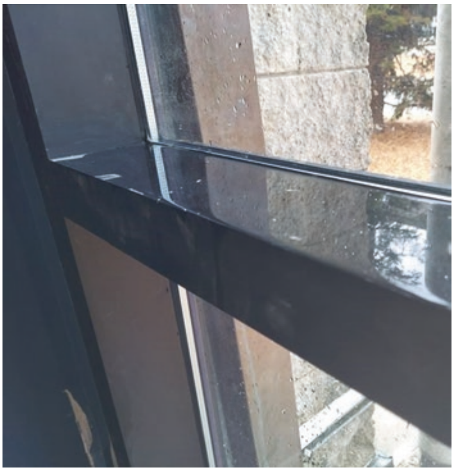


Fig. 4 Water infiltration with a pressure of 25,06 psf. (Credit: TCLab)

5.3 Water-Tightness Performance Under Dynamic Pressure

The test consists of applying a constant and uniform amount of water to the outer surface of the Mock-Up and the simultaneous application of dynamic pressure to record any water infiltration. The environmental parameters of the laboratory during this test are: temperature 12.1 °C, relative humidity 30.8%, and atmospheric pressure 99.8 kPa. The dynamic test is performed using the dynamic axial fan (hurricane simulator) capable of replicating the turbulent wind and rain loads on the building systems and is able to generate wind speeds of approximately 220 km/h. The test is conducted by applying a dynamic pressure of 31.5 lbf/ft^2 (pounds per square foot), 1508 Pa and an amount of water equal to 5 US gallons per square foot in an hour (= 3.4 l/min m^2) to the Mock-Up for 15 minutes. Wind-driven rain and wind pressure are two crucial climatic parameters affecting the infiltration of water through building facades. A feature of this test is that water can be injected into the wind stream to simulate the dynamics of wind-induced rain. Under extreme wind conditions, the Mock-Up responds positively as the pressure generated by the fan disperses the water flow over the façade, preventing accumulation and infiltration within the curtain wall (positive feedback) (Fig. 5). This analysis shows that high rainfall intensities do not generally coincide with high wind speeds; to have reliable boundary conditions, it is necessary to consider these variable effects.

The data do not identify any critical behavior of the curtain wall about the simulated phenomena, pointing to positive and flexible reaction behavior. Therefore, as an adaptation strategy for curtain wall systems, it is necessary to develop adaptive models as serial components to be applied in the façade to improve performance to

Fig. 5 Mock-Up tested for water-tightness under dynamic pressure (external and internal view). (Credit: TCLab)

external stresses, avoiding the creation of more severe damage that may compromise the overall functioning of the system.

In particular, the idea of the adaptive model to be applied on these types of façades will have a twofold feedback in the progress of the research: on the one hand, to guarantee acceptable levels of safety with respect to environmental flows and external stresses (specifically for heatwaves and precipitation in the Mediterranean area), which relate to the building envelope, and on the other hand, to have spin-offs at a technological level toward innovative solutions that have been tested and verified, according to standardized test protocols, which can be replicated in specific contexts of intervention, such as the one studied. The definition of an adaptive curtain wall, climatically verified, could also help define the maximum amount of energy savings that can be achieved, stimulating the need to develop new materials, technologies, and products for building envelope facades. This is due to the fact that an adaptive façade is more effective in minimizing cooling energy demand, which is more relevant in the climate of the Mediterranean area. The results of this study could be particularly useful to orient the future development of adaptive façade technologies.

6 Conclusions and Future Development

From these analyses, the following conclusions derive from the first part of the experimental activities. This study is carried out to investigate the actual performance of a curtain wall under extreme climatic conditions in the Mediterranean area, to identify performance deficits and develop a possible congruent adaptive solution. From a review of the state of the art, the current curtain walls guarantee verified performance level against standardized average values of service conditions, resulting in envelopes that have the same performance even under different contextual conditions. Although the system passed performance tests, the results and evaluations of this experimental research—on full-scale mullion and transom curtain wall Mock-Up—show how deficiencies or failures can occur during their service life, especially during extreme precipitation. Therefore, this research, although still ongoing, is oriented toward the definition and prototyping of the optimal combination of the adaptive model through the use of intelligent shape memory materials, focusing on the most appropriate adaptive efficiency, calibrated against specific environmental contexts. The subsequent phases of the research are based on the verification of the technical feasibility, constructability, and technological characterization of the adaptive model to be tested. The adaptive module could represent an innovative solution, due to its technological characteristics, able to respond to the requests of building industry and enabling the achievement of the EU's climate change mitigation and adaptation goals. Performance verification of the adaptive model, in dynamic regime, has the final objective of developing prototype lines that can facilitate the new approach to adaptive envelopes with high environmental quality. In this sense, testing activities offer designers and engineers' guarantees on the reliability and conformity of data and results and empower technology transfer mechanisms through the systemic use of research results by the production sector. A line of future development of this research could be the verification of the thermodynamic characteristics of the model, through the use of the Test Cell of the TCLab Section, to determine the thermal transmittance, thermal bridges and the fluid-dynamic behavior, due to different internal and external stresses.

References

1. IPCC. (2021). *Climate change 2021. The physical science basis. Summary for policymakers. Working Group, I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Online: https://ipccitalia.cmcc.it/messaggi-chiave-ar6-wg1/–. Accessed on 15 June 2022.
2. Galbiati, F. (2019). *Incendi in Siberia e il concetto di "feedback climatico". Icona Clima, 01/08/2919.* Online: https://www.iconaclima.it/salute-del-pianeta/temperature/incendi-in-siberia-e-il-concetto-di-feedback-climatico/–. Accessed on 3 June 2022.
3. United Nations Environment Programme. (2021). *2021 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector*.
4. Europea, C. (2019). *Il Green Deal europeo. Comunicazione della Commissione al Parlamento Europeo, al Consiglio, al Comitato Economico e Sociale Europeo e al Comitato delle regioni*. Bruxelles, COM (2019), 640 final.
5. Li, L. (2021). Integrating climate change impact in new building design process: A review of building life cycle carbon emission assessment methodologies. *Cleaner Engineering and Technology, 5*, 100286.
6. MedECC. (2020). In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and environmental change in the Mediterranean Basin – Current situation and risks for the future. First Mediterranean assessment report* (p. 632). Union for the Mediterranean, Plan Bleu, UNEP/MAP. ISBN: 978-2-9577416-0-1.
7. Gaertner, M. Á., González-Alemán, J. J., Romera, R., Domínguez, M., Gil, V., Sánchez, E., et al. (2018). Simulation of medicanes over the Mediterranean Sea in a regional climate model ensemble: Impact of ocean–atmosphere coupling and increased resolution. *Climate Dynamics, 51*(3), 1041–1057.
8. Yalaz, E. T., Tavil, A. U., & Celik, O. C. (2018). Lifetime performance evaluation of stick and panel curtain wall systems by full-scale testing. *Construction and Building Materials, 170*, 254–271.
9. Song, Y. W., Park, J. C., Chung, M. H., Choi, B. D., & Park, J. H. (2013). Thermal performance evaluation of curtain wall frame types. *Journal of Asian Architecture and Building Engineering, 12*(1), 157–163.
10. Fragkia, V., & Foged, I. W. (2022). Occupant-oriented adaptive building envelopes: A hybrid design framework for human, material, environment synergies. In *Structures and architecture. A viable urban perspective? Proceedings of the fifth international conference on structures and architecture (ICSA 2022), July 6-8, 2022, Aalborg, Denmark* (p. 430). CRC Press.
11. Aelenei, D., Aelenei, L., & Vieira, C. P. (2016). Adaptive Façade: concept, applications, research questions. *Energy Procedia, 91*, 269–275.
12. Loonen, R. C. G. M., Rico-Martinez, J. M., Favoino, F., Brzezicki, M., Ménézo, C., La Ferla, G., & Aelenei, L. (2015). Design for façade adaptability–towards a unified and systematic characterization. In *Proceedings of 10th energy forum-advanced building skins, Bern, Switzerland* (Vol. 1274, p. 1284).

13. Bedon, C., Zhang, X., Santos, F., Honfi, D., Kozłowski, M., Arrigoni, M., & Lange, D. (2018). Performance of structural glass facades under extreme loads–design methods, existing research, current issues and trends. *Construction and Building Materials, 163*, 921–937.
14. Hosseini, S. M., Mohammadi, M., Schröder, T., & Guerra-Santin, O. (2020). Integrating interactive kinetic façade design with colored glass to improve daylight performance based on occupants' position. *Journal of Building Engineering, 31*, 101404.
15. Hosseini, S. M., Mohammadi, M., Rosemann, A., Schröder, T., & Lichtenberg, J. (2019). A morphological approach for kinetic façade design process to improve visual and thermal comfort. *Building and Environment, 153*, 186–204.
16. Conato, F., & Frighi, V. (2018). Il ruolo dell'innovazione nella definizione di nuovi paradigmi formali in Architettura. *TECHNE: Journal of Technology for Architecture & Environment, 16*, 105–112.
17. Borkowski, E., Rovas, D., & Raslan, R. (2021). Adaptive building envelope simulation in current design practice: Findings from interviews with practitioners about their understanding of methods, tools and workarounds and implications for future tool developments. *Intelligent Buildings International*, 1–18.
18. Attia, S., Favoino, F., Loonen, R., Petrovski, A., & Monge-Barrio, A. (2015). Adaptive façades system assessment: An initial review. In *10th Conference on Advanced building skins*, (pp. 1265–1273). ISBN/EAN :978-3-98120538-1, Munich, Germany.
19. Gonįalves, M. D., Jutras, R., & Velji, M. (2010). *Evaluating the field performance of windows and curtain walls of large buildings*. Symposium on building envelope technology, Nov 2007, pp. 57–65.
20. Trombetta, C., & Milardi, M. (2015). BUILDING FUTURE Lab.: A great infrastructure for testing. *Energy Procedia, 78*, 657–662.

Seismic Evaluation of a Curtain Wall System for Improving the Adaptive Performance of Connecting Nonstructural Components

Massimo Rossetti, Martino Milardi, and Sara Sansotta

1 Introduction

In recent decades, the emblematic relationship between the environment and buildings, in a key that investigates aspects of safety, comfort, and sustainability, has become a driver of technological innovation, especially concerning the performance potential of the vertical enclosures that constitute the built environment. The advancement of technological progress, due to process innovations in processing and prototyping techniques resulting from the fourth industrial revolution, has changed the traditional design paradigms of the building process. This has resulted in a wide range of crosscutting [1] and high-performance technological solutions, which, however, have difficulty confronting increasingly limited and outdated regulatory frameworks.

In this process of innovation, the evolved functionalization of the building envelope becomes the main focus of various experimental researches, the purpose of which is related to the possibility of managing the effects of the dynamic response of the context in which the system is grafted [2]. The technological component significantly contributes to the definition of a new architectural language. The aptitude for generating architectures with responsive capabilities to cope with modern demands for change inevitably involves a transition of formal paradigms. In this sense, architects and technologists are required to broaden their skills. They are called upon not only to rethink the functional-performance characteristics of the

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components that constitute the building envelope but also to modify the design process through contamination from technology transfer from other areas of science and technology.

These processes have enshrined the etymological and performance transition of envelope systems. To the three traditional types—conservative, selective, and regenerative—identified by Banham [3], a fourth has been added: the adaptive envelope [4]. Frei Otto first describes adaptive architecture as a system that can change shape, position, use, or space [5]. Indeed, adaptive façades can improve the energy efficiency and economy of buildings through their ability to change their performance and behavior in real time, based on indoor-outdoor parameters, through materials, components, and systems [6]. The adaptive behavior of building envelopes has so far been widely debated on energy-environmental issues [7]. In recent decades, the meaning of adaptivity is broadened and further declined toward new purposes, including the ability of façade systems to change their morphology by structurally supporting themselves and not overloading the primary supporting structure. Indeed, an important function of façades is to transfer various design loads and consequently facilitate the response to movements due to the same actions, such as seismic loads [8].

The challenge is focused on advancing knowledge in the field of experimenting with curtain wall systems that can respond adaptively to seismic loads, even during the preliminary stages of the design process. However, structural adaptability can lead to a more efficient static and dynamic response under varying load conditions, i.e., increase strength during extreme events and/or provide *fail-safe* collapse mechanisms [9], thus improving structural robustness. Implementing these increasingly adaptive and responsive technologies results from the impressive use of simulation and modeling software that can overcome some formal limitations due to traditional design tools and through which increasingly complex forms can be developed.

The envelope releases itself from the primary structure. It acquires new specificities dictated by the need to configure itself as an osmotic membrane, capable of changing its adaptive material behavior as external stresses change, minimizing impacts and vulnerabilities resulting from extreme events. Specifically, the action due to exceptional loads such as seismic events, from a structural point of view, is a critical component, especially in the case of glazed systems, due to the typically brittle behavior and limited tensile strength of glass sheets, as well as insufficient connection details [10]. The need to extend the seismic design to the nonstructural elements of the building stems from the observation of the technical and economic damage due to the loss of strength not only of the structural system but especially of the façade system in the case of insufficient connection details and large inter-story drifts [11]. It is appropriate for the design of nonstructural elements to be based on the understanding that these, when stressed to the load of the earthquake, become structurally responsive and transfer lateral loads to the primary supporting structure, causing an interruption of performance for environmental requirements, which affect the proper use of the building, but also of service conditions, interrupting their functionality, for the safety of the occupants.

In this scenario, Industry and Research are called upon to collaborate to implement *technology-push* innovation, the common goal of which is to design and implement building envelopes capable of being contextually responsive to changing external stresses. The study and analysis of the dynamic behavior of nonstructural curtain wall elements under seismic action is the focus of an ongoing Industrial Doctoral Research conducted at the Mediterranea University of Reggio Calabria. The overall objective aims to advance knowledge and experimentation in the field of flexible connections.

Outlining the functional-material characteristics of nonstructural components with seismic mitigation technologies to be implemented in a curtain wall stick system, a specific objective will allow the entire system to be rendered as a damping device. The contribution, therefore, is related not only to experimentation in the design field but to spillover effects on performance in terms of the environment, permeability to air, water, thermoregulation, and in terms of response to catastrophic events such as seismic events, also in line with Cluster 3, *"Improved disaster risk management and societal resilience"* within the PNR 2021-2027 and Trajectory 2 of S3 Calabria.

2 The Adaptive Character of Envelopes for Seismic Stresses

Derived from disciplinary fields such as architecture and engineering, terms such as *"smart," "intelligent," "interactive," "adaptive,"* or *"responsive"* while overused, respond to different terminological meanings. To further restrict the scope of the investigation, the term adaptive is grasped as a multifunctional system capable of changing its functions, characteristics, or behavior over time in response to transient performance requirements and boundary conditions, to improve the overall performance of the building [12]. From the scientific background, the focus is on different types of flexible structures to frame current deficits and define new opportunities related to designing adaptive components. The behavior of nonstructural elements during catastrophic environmental events is becoming of great interest in the scientific community [13]. Adaptation and response to changing circumstances are only possible by applying flexible structures [14]. In general, multidisciplinary approaches and specific fail-safe design criteria are needed, including advanced analysis methods that can take into account the inherent properties of the curtain wall system, which can cause devastating effects with not only economic losses but also especially with the loss of life.

Indeed, such design must consider purely structural requirements to improve the response of a given façade system under an assigned load configuration, as well as thermal, economic, social, and technological variables. In the field of seismic design of building envelopes, structural features used in building design are often taken up. As early as the 1970s, building design in Japan was based on the plastic rotational capacity of the structure; with this in mind, various types of damping devices were developed. These devices are generally integrated into the structures, becoming constituent elements of the design, to optimally reduce building vibrations due to earthquake and/or wind loading [15]. This design mainly produces elastic behavior during an earthquake so that seismic energy is absorbed by the energy-absorbing elements embedded in the structure of each floor [16]. Improving the performance of façade systems has been relied upon, especially in the case of double-skin façades, to apply such devices [17]. Some critical limitations for the adoption of this solution for curtain wall systems reside not only in high costs but also in the difficulty of the design, high-dimensional characteristics as well as practices of not easy maintainability, being in most consist of a series of elements, such as actuators and sensors [18].

In a synthesis framework developed through the critical analysis of systems equipped with these devices, the hypothesis was put forward to evaluate the façade's ability to act as an energy-absorbing device, assuming the optimal value of the properties of façade dampers [19]. This is carried out from a perspective that aims to innovate design processes for curtain wall systems with particular reference to the materials that make up the frame-façade and supporting structure connection elements, so that they are able to withstand deformations due to earthquake action, in order to manage the response of vibration effects on buildings, and even mitigate stresses on the primary supporting structure.

3 The Experimentation: Adaptive Performance of Connecting Nonstructural Components

From the analysis of the case studies carried out for the development of the research on the effects induced and suffered by façade systems subjected to seismic events and the functional-typological characteristics of the solutions adopted for the improvement of these systems, with particular reference to damping devices, the project aims to analyze the causes of the criticalities arising during such phenomena.

The methodology of the research adopts a deductive, systematic, and scalar model, structuring a thematic frame of reference, moving from the definition of the macro-theme, defined by the problems related to the envelope subject to seismic action, to the identification of the adaptive characteristics of nonstructural components, with particular reference to the façade connection systems that fulfill the functional properties of dampers. To exhaustively carry out the research methodology, it is specified that the experimentation is carried out for the type of stick system *"WS50 Curtain Wall,"* produced by the company Ponzio S.r.l., and the connecting used for the given system. Through accurate analysis methods, verifications will be carried out concerning the dynamic behavior due to the stresses of the earthquake action. Specifically, the curtain wall stick system or mullion and transom is based on vertical and horizontal elements, usually made of aluminum, forming a structural grid to which the curtain walls, transparent or opaque, are applied.

The contribution concerns the discussion of ongoing experimental research, so the methodological steps described in the following paragraphs concern steps that have already been initiated for experimentation and the reporting of actions that are yet to take place in the coming months. The façade performance evaluations are conducted through two steps, given two portions of the stick system façade designed with the support of the supplier company; the first step concerns modeling and finite element analysis through SimSolid simulation software, provided by the partner company Altair Software and Service SL; the second concerns the verification of the façade systems through normed testing procedures through the Testing laboratory, TCLab of the Building Future Lab in Reggio Calabria.

Having built the framework of synthesis in which the criticalities of current connection elements subjected to seismic loads emerge, the research focused on the study of *smart materials*, which can change their physical-formal properties according to the imposed actions. Recent material innovations are strongly related to the innovative conception of the building envelope. The purpose of which is related to the design and implementation of elements with *fail-safe* adaptive capabilities, capable of adjusting their configuration or physical properties in response to changes in internal and external conditions. The material composition of building components and systems has, therefore, assumed a key role during the design stages, seeing itself forced to give way to performance potential. In this sense, great attention is being paid to the evolution of materials with SMA shape memory effects and SE super elastic effects [20]. The focus, then, is on the material's ability to generate reversible motion and transfer adaptive capabilities to the entire system, constituting a single element in what is often implemented by incorporating increasingly complex and computerized actuators and sensors. These materials, applied to the design of components whose function is to absorb and dissipate energy from exceptional loads, such as seismic loads, are capable of imparting great deformation capacity to the entire system.

This is made possible through the mechanical compatibility between the building structure and curtain wall systems, as opposed to the common practice of relying on seismic resistance to the joints present between the elements that constitute the façade. The design and modeling of the flexible connection element have the ultimate goal of performance verification under service and safety conditions. The superposition of the results obtained from the simulation and Testing steps will allow defining a new design methodological approach, in which the design costs and time could be halved, thanks to the implementation of advanced software.

3.1 Technical Specifications of Mock-Ups for Constructing Variables for the Simulation and Testing Phase

The chosen configuration of the mullion and transom curtain wall system subjected to analysis and verification for the simulation and testing phases is identical. Specifically, two stick system type specimens were designed with variable span configurations, which are the same dimensional characteristics but different in the

Table 1 Technical characteristics of Mock-Ups

Profile		Curtain Wall WS50 Ponzio
Dimension		2 Mock-Ups: 3050 mm (W) × 6860 mm (H)
Frame Façade	Mullion	50 mm × 125 mm (Extruded bar)
	Transom	50 mm × 129.5 mm (Extruded bar)
	Thermal Break	Polyamide Spacer
Glass		Insulated Glass 55.2 + 16 + 55.2
Glass gaskets		EPDM interior and exterior
Dimensions openable to overhang		1800 mm (W) × 1700 mm (H)
Tilt and turn door opening dimensions		1250 mm (W) × 1700 mm (H)
Glass entrance		13 mm
		10 mm
Transom–mullion connection elements		Aluminum push-button jumper
		Aluminum round connecting bracket
Anchorage systems		Steel square tube 200 mm
		Anchorage stirrups mullions

technological arrangement of the mullion. In fact, in the first specimen, the mullions will have a broken axis, while in the second case, the mullion will have a single axis. As described in Table 1, the Mock-Ups, to be analyzed by SimSolid software and tested in the test chamber of the TCLab section, are designed with 125 mm single-axis and broken-axis mullions and 129.5 mm transoms, whose overall dimensions are 6570 mm (Width) × 6860 mm (Height) (Fig. 1). For the implementation of different variables within a single Mock-Up, mullions and transoms were arranged asymmetrically, configuring variable height and long spans. As a result, 12 sets of mirrors and, two types of openers per Mock-Up tilt and turn sash and projecting openers.

3.2 Simulation Phase

The development of the first methodological step of the experimental phase involved modeling Mock-Ups on parametric 3D software (Inventor), going to identify the simplification steps useful for reading the model on SimSolid Software.

The first development steps focused on classifying the boundary conditions (Fig. 2), which identify and simulate the real environment, the geometric simplification of the Mock-Up elements, and studying their material characterization. The reading of all the elements that make up the curtain wall system focused on two aspects, EPDM seals, understood as critical elements both for the creation of the connections on SimSolid software and for the reading of the material characterization of these elements, and the presence of windows within the specimens.

For the first aspect, we proceeded toward two types of connections:

- *"Bonded,"* understood as solid connections between the various aluminum elements, which give the system additional rigidity between the various elements

- *"Sliding without friction,"* understood as connections that allow a degree of freedom in vertical or horizontal translation

For the presence of openers, however, it was necessary to break down and simplify all the accessories that make up the opening systems. Subsequently, initial analyses were developed, including modal analysis to verify the state of the connections made on the software and initial linear (Fig. 3) and nonlinear dynamic structural analyses to classify the behavior of the simulated specimen subject to seismic actions.

From the analyses conducted so far, it has become apparent that the limitations associated with software, which is mainly used for conducting finite element

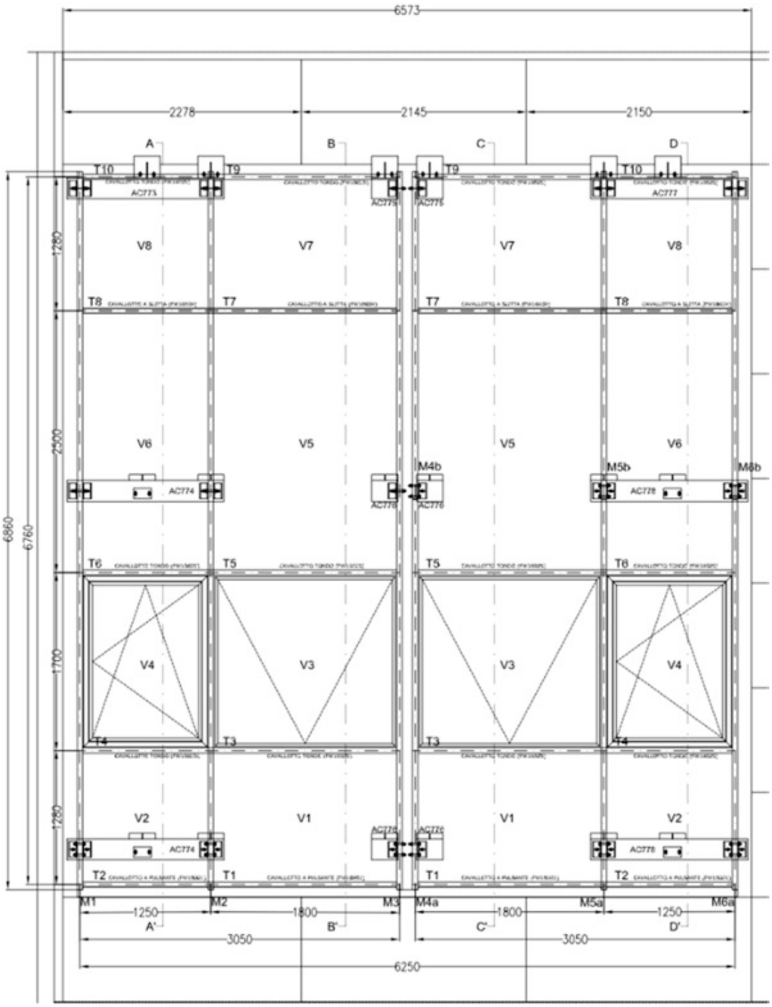

Fig. 1 Technical specification of Mock-Ups

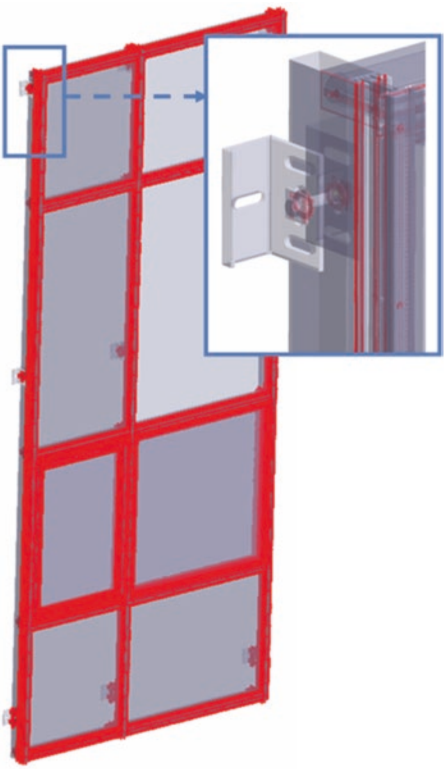

Fig. 2 Creating connections on SimSolid software

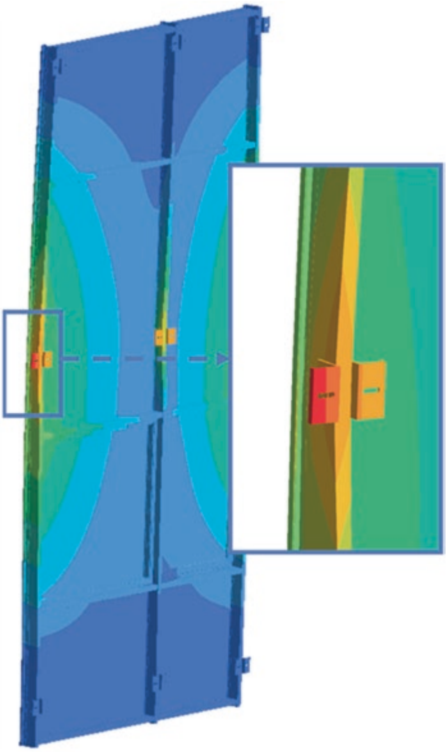

Fig. 3 First linear analysis on Mock-Up 1

analyses of structural systems, are unable to simulate the real behavior of the stressed system. In the specific case, the torsional behavior of the mullion is not congruous with the static verifications developed in the design phase. In this sense, it is essential that the sealing elements are further studied in the type of connections and their material characteristics. Simplification of the elements and continuous feedback with the software developers has as its ultimate goal the implementation of the performance of the software so that it is able to analyze the façade systems.

3.3 Testing on Mock-Up

For the second experimental phase, the design phase of the Mock-Ups to be tested was initiated with the support of the TCLab section, following standardized protocols. During the study and analysis activities for the design of the Mock-Up to be tested, the dimensions of the actual state of the test chamber were evaluated. The expected results concern the reading of the dynamic behavior of the commercial façade of Ponzio S.r.l., so that it can be improved under the seismic aspect.

Technical drawings and bills of materials/elements to be fabricated have been prepared, focusing on the design of the connection elements useful for placing the specimen inside the test chamber, returning a real condition of the façade system. The configuration of the typological arrangement of the Mock-Ups followed with the design of their placement within the TCLab test chamber, so as to evaluate the relative distances to the chamber's movable beams and to the Mock-Up mullion floor anchorage bracket (150 mm) and design accordingly an anchorage system to the movable and seismic beams of the test chamber.

If in the simulations phase the analyses will be conducted for the safe conditions by simulating the displacements that are imposed for the normed procedures of seismic stresses, in the case of the laboratory tests the specimens will be respectively stressed for the service conditions with respect to the European air, water, and wind permeability standard, but also in the safe conditions, following the American 501.6-09 *"Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System"* standard (Table 2) (Fig. 4).

Table 2 Method Statement Project Mock-Up

Air permeability	UNI EN 12153:2002
Water-tightness under static pressure	UNI EN 12155:2002
Resistance to wind load—100% functionality	UNI EN 12179:2002
Static seismic test	UNI EN 13830:2015
Repeats Air permeability Water-tightness under static pressure	 UNI EN 12153:2002 UNI EN 12155:2002
Resistance to wind load—safety 150%	UNI EN 12179:2002
Dynamic Racking Crescendo Test	AAMA 501.6-01

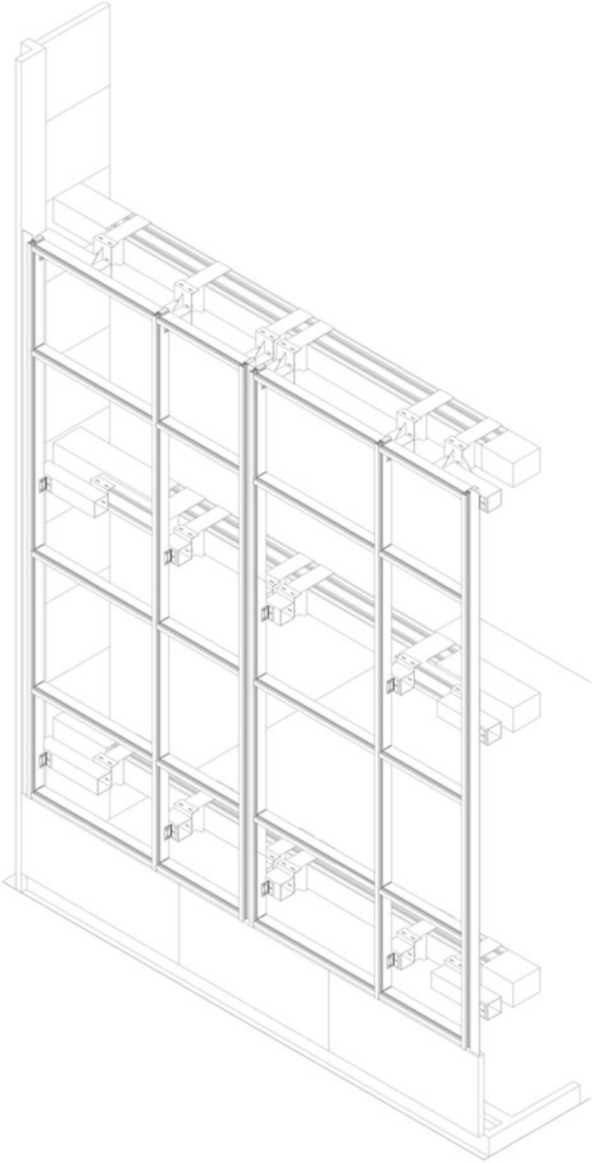

Fig. 4 Mock-Up placement within the TCLab section test chamber system

The conclusion of the experimental part aims to verify the current performance of the stick system façade under seismic stress through the possible superimposition of the results obtained through simulation activities with SimSolid software and testing activities with the contribution of the TCLab section of the Building Future Lab.

4 Conclusion

In apparent antithesis to each other, Simulation and Testing are called upon to compete with the design phases concurrently. Once again, we see the fundamental role of prediction by the possible damage due to the collapse or failure of façade elements. Testing, in specialized laboratories, on the other hand, will turn out to be a fundamental step to read the real behavior of the stressed façade system, parameterizing all the critical factors such as strength and fragility, to formulate data sheets that can be read depending on the performance to be asseverated or implemented to a given system.

In this sense, experimentation becomes a fertile field of product innovation, as a designed technology apt to improve seismic performance and a methodology capable of streamlining curtain wall design procedures to ensure products with increased performance. The interdisciplinary nature of the research allows for the development of a cross-disciplinary study among various disciplines, such as architectural technology, civil engineering, and materials science, which can implement experimental processes related not only to the design of nonstructural components but also to the characteristics that can make them dynamic/adaptive. In this scenario, it is intended to emphasize the importance of strengthening research and fostering the dissemination of innovative models for research conducted between universities and enterprises to support innovation and technology transfer processes.

The collaboration for the industrial Ph.D. is intended as an exchange of results and inputs with companies with spillovers to increase knowledge in the field of seismic design and the use and implementation of simulation software, which have been used so far mainly for structural components analysis cases. The variables related to the results obtained from the experimental phases of the research open up some scenarios for future developments. In fact, in the steps following the research, on the one hand, the validity and design process of the component will be verified. On the other hand, we will aim to direct the research toward prototyping the nonstructural component of the building envelope. In this sense, the purpose of innovating the design processes for the implementation of façade systems is closely related to the innovation of the product that can be started toward the industrialization stage, investigating its possible validity for other types of façade systems.

References

1. Conato, F., & Frighi, V. (2018). Il ruolo dell'innovazione nella definizione di nuovi paradigmi formali in Architettura. *TECHNE: Journal of Technology for Architecture & Environment, 16*.
2. Mazzucchelli, E. S. (2018). L'involucro di edifici complessi: aspetti progettuali e costruttivi. *Modulo, 415*, 78–83.
3. Banham, T. M. (1969). Indications for tonsillectomy. *British Medical Journal, 1*(5643), 573.

4. López, M., Rubio, R., Martín, S., & Croxford, B. (2017). How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes. *Renewable and Sustainable Energy Reviews, 67*, 692–703.
5. Otto, F., & Rasch, B. (1995). *Finding form*. Axel Menges.
6. Romano, R., Aelenei, L., Aelenei, D., & Mazzucchelli, E. S. (2018). What is an adaptive façade? Analysis of recent terms and definitions from an international perspective. *Journal of Façade Design and Engineering, 6*(3), 65–76.
7. Rossetti, M. (2019). *L'involucro architettonico contemporaneo*. Maggioli Editore.
8. Bedon, C., Honfi, D., Machalická, K. V., Eliášová, M., Vokáč, M., Kozłowski, M., et al. (2019). Structural characterisation of adaptive façades in Europe–part I: Insight on classification rules, performance metrics and design methods. *Journal of Building Engineering, 25*, 100721.
9. Feldmann, M., Kasper, R., Abeln, B., Cruz, P., Belis, J., & Beyer, J. (2014). *Guidance for European structural design of glass components* (pp. 1–196). Publications Office of the European Union.
10. Bedon, C., & Amadio, C. (2018). Numerical assessment of vibration control systems for multi-hazard design and mitigation of glass curtain walls. *Journal of Building Engineering, 15*, 1–13.
11. Nakai, M. (2015). Advanced structural technologies for high-rise buildings in Japan. *CTBUH Journal, No. 2*, 22–29.
12. Loonen, R. C. G. M., Rico-Martinez, J. M., Favoino, F., Brzezicki, M., Ménézo, C., La Ferla, G., & Aelenei, L. (2015). Design for façade adaptability–towards a unified and systematic characterization. In *Proceedings of 10th energy forum-advanced building skins, Bern, Switzerland* (Vol. 1274, p. 1284).
13. Rizzo, F., Franco, A., Bonati, A., Maddaloni, G., Caterino, N., & Occhiuzzi, A. (2021). Predictive analyses for aerodynamic investigation of curtain walls. *Structure, 29*, 1059–1077. Elsevier.
14. Chloë, M. (2016). *Structural adaptive façades*. (Master's Dissertation). Ghent University, Ghent.
15. Lago, A., Trabucco, D., & Wood, A. (2018). *Damping technologies for tall buildings: Theory, design guidance and case studies*. Butterworth-Heinemann.
16. Hareer, R. W. (2007). *Seismic response of building façade system with energy absorbing connections* (Doctoral dissertation, Queensland University of Technology).
17. Pipitone, G., Barone, G., & Palmeri, A. (2018). Optimal design of double-skin façades as vibration absorbers. *Structural Control and Health Monitoring, 25*(2), e2086.
18. Abtahi, P. (2017). *Energy dissipating façade systems designed to reduce structural response during earthquakes* (Doctoral dissertation, Western Sydney University (Australia)).
19. Lee, H., Oh, M., Seo, J., & Kim, W. (2021). Seismic and energy performance evaluation of large-scale curtain walls subjected to displacement control fasteners. *Applied Sciences, 11*(15), 6725.
20. Seo, J., Kim, Y. C., & Hu, J. W. (2015). Pilot study for investigating the cyclic behavior of slit damper systems with recentering shape memory alloy (SMA) bending bars used for seismic restrainers. *Applied Sciences, 5*(3), 187–208.

Process Management of Spatial Structures to Address Positive Buildings with the Goals of Sustainable Development

Zinat Javanmard and Stefano Cascone

1 Introduction

By 2050, the EU aims to become a Union where buildings will no longer emit greenhouse gases. The traditional building design process is becoming ineffective in meeting new sustainability challenges, which calls for a fundamentally different and more advanced design process [1].

The building sector accounts for 30% of global final energy consumption [2] and nearly 50% of all resource extraction [3]. It also generates large amounts of construction and demolition waste (CDW), equivalent to nearly 40% of annual extracted construction materials [3, 4].

This target needs integrated design approach that the role of the iterative process is necessary [5]. A widely accepted concept in the design community is that high-performance projects require intense interdisciplinary collaboration to ensure that building systems are synergistic and "right sized" [6]. The need for high-performance buildings illustrates the fact that traditional design systems no longer answer current needs for decreased environmental impacts, as precise design decisions are not fully understood in the early stages of decision-making. The traditional building design is an evolutionary process where the detailed design decisions are not fully known at early stages [7].

Spatial structures by using new technologies and lightening and by applying scientific and applied concepts in design and execution, as well as observing seismic safety requirements that lead to the durability and stability of the structure, play

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an important role in reducing environmental pollution, especially performs in massive projects.

The aim of this research is to define parameters evaluating the contribution and limitation of strategies by defining a managerial view of the spatial structure process to optimize energy consumption, pointing out the climatic design as a solution to improve the efficiency as structures with the potential for positive buildings. This requires a complete understanding of all the processes of spatial structures from initial studies to the operational period.

From the perspective of the author in this article, the proposed solution to this challenge is the existence of a comprehensive and energetic system in which all stages of the building construction life cycle are considered. In this system, the commitment to the protection and care of the environment is increased and an optimal balance is established between costs, environmental, social, and human benefits. The goals of the proper building design are to avoid wasting energy, water, and raw materials, prevent environmental degradation, reduce climate heat, reduce carbon emissions, and ultimately create a safe, livable, comfortable, and resilient environment.

Regarding the integrated design process (IDP), all of them as an innovative and collaborative design approach for green building (GB) delivery have gained recognition in practice over the past decade.

Michael et al., in their paper “Delivering Green Building: Process Improvements for Sustainable Construction,” define an emerging research and education program at Penn State called the Lean and Green Initiative. Focused on understanding all aspects of the delivery of high-performance projects, this program is underpinned by established process-based theories and structured around a systematic methodology designed to minimize waste, maximize value, and reduce cost. Current research and educational activities are described in the paper including nine primary research thrusts and their respective goals [6].

“Assessing environmental performance in early building design stage: An integrated parametric design and machine learning method” is research that has been done by Kailun Feng and his coworkers in 2019. They developed a method to quantify and map uncertainty in the early design stage. They showed that designers can evaluate and compare the performance of early design scenarios. This was an innovative way to connect parametric design and machine learning algorithms [7].

Lapinskiene and Motuziene in research as “Integrated building design technology based on quality function deployment and axiomatic design methods” presented the newly developed technology of the design concept of the building, which integrates design methods, digital design and simulation tools and the principles of IBD that are well known in common engineering. The validation of the proposed technology has shown that the technology requires fewer design iterations, and the main requirement is fulfilled to a greater extent (by way of lowering energy consumption) [8].

Spatial structure has different types of connections with various methods that allow designers to create different forms in terms of form and shape. This capability encourages the designer to use these structures in different applications on the big project. On the other hand, a key tenet of lean construction is the expanded use of prefabrication due to the production advantages of prefabrication environments [9]. These structures with the prefabricated potential have a great capability to design as a lean construction. The location and function of a building, flexibility, orientation, shape, structure, type of heating and cooling system, ventilation, and the materials used are different factors affecting the amount of energy consumption for construction, operation, maintenance, and transportation, so with considering these items during the different sector of designing and construction ultimately can lead to the sustainable architecture [2].

As the Architecture, Engineering, and Construction (AEC) industry develops the strategies and technologies for different projects, an increased emphasis must be placed on the processes and competencies required to deliver high-performance buildings, and it is necessary for spatial structures too, as structures with most pottentional to high-performance buildings.

Due to the complexity of the process of spatial structures, despite the different capabilities of these structures, there are many reasons for wasting energy in these structures from starting the process of designing to operation and maintaining. Furthermore, given the importance of considering environmental issues in construction projects, this should be a concern for engineers working in the field of spatial structures. Unfortunately, the issue of energy efficiency in spatial structures, as well as the various capabilities of climate design, has received less attention in the process of these structures, and no effective research has been done in this field. This is a significant challenge in the field of environmental protection. To achieve the sustainable goals without the existence of an integrated process that makes an effective connection between all sections of design and construction buildings cannot be operative.

Due to design Spatial structures with a positive paradigm and sustainability goals, the existence of an integrated design system that shows the process of these structures from the beginning of the initial studies to the period of operation can be effective because the existence of integrated design technique on the designing process of spatial structures can eliminate the drawbacks of traditional building design, and to ensure a sustainable and customer-oriented design solution, the existence of an integrated diagram can decrease primary energy demand with less design iterations to match the initial project requirements. The structured diagram of the technology facilitated the communication between project groups.

Minimizing or maximizing a function means that this function is a measure of the design process, which improves efficiency in preventing energy and material wastage. Figure 1 shows the optimization charter.

Optimization can be defined in different areas—optimization in energy consumption, structural optimization, economic optimization, use of manpower, etc. In this article, since one of the basically goals of sustainability is optimization, and sustainability is the first step to access the high-performance building, the beginning of the design process has been based on the issue of optimization and the main diagram has been started from the optimization chart.

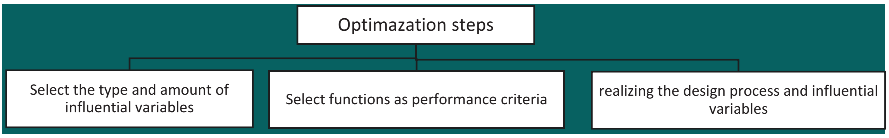

Fig. 1 The optimization charters

2 Methodology

In this article, the authors have tried to identify gaps and shortcomings in the field of sustainable architecture in spatial structures by studying and reviewing research in the field of positive buildings and integrated management system, and by introducing various factors affecting the sustainability aspects of these structures. It is presented a process diagram for spatial structures and its relationship with the discussion of optimizing an integrated management system for the process of these structures. The existence of an extensive and effective system in which all stages of the building construction life cycle are considered. In this system, the commitment to environmental protection and care is increased and an optimal balance is established between costs, environmental, social, and human benefits. The goals pursued in the proper design of the building are avoiding the loss of energy resources, water, and raw materials, preventing environmental degradation, and ultimately minimizing building pollution during operation (positive building approach). The process of spatial structures consists of four stages [10]: (1) design of spatial structures process, (2) construction of spatial structures process, (3) carrying spatial structures process, and (4) assembling and installation of spatial structures process.

2.1 Design of Spatial Structure

Design of spatial structure sequential process includes the selection, and the other part includes calculations and numerical studies. Considering that to approach the optimal design, it is necessary to consider all the relevant options, and taking into consideration the variety of researchable choices while constructing a spatial structure. Despite having sophisticated computers, determining the best alternative for a spatial arrangement is typically not straightforward.

To integrate the design process: the process of designing spatial structures includes the following: (a) to design the form, (b) to design the construction method, (c) to design the texture and installation, (d) to design how to transport and transfer to the place, and (e) to design the maintenance method.

(a) *To design the form as a multi-step process:* Architecture and structure are two processes that must be done in parallel; Fig. 2 shows the multi-step process of form designing.

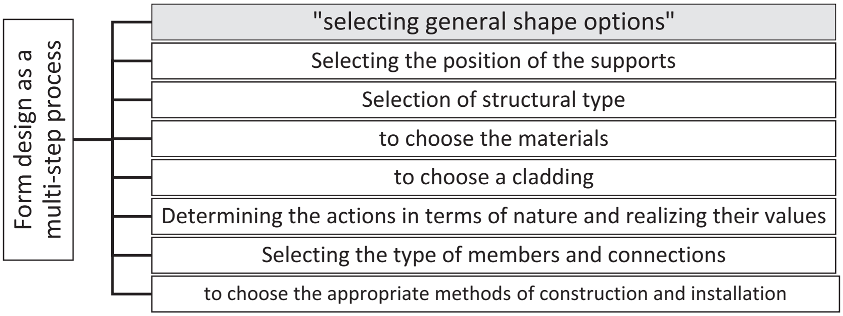

Fig. 2 Form design process

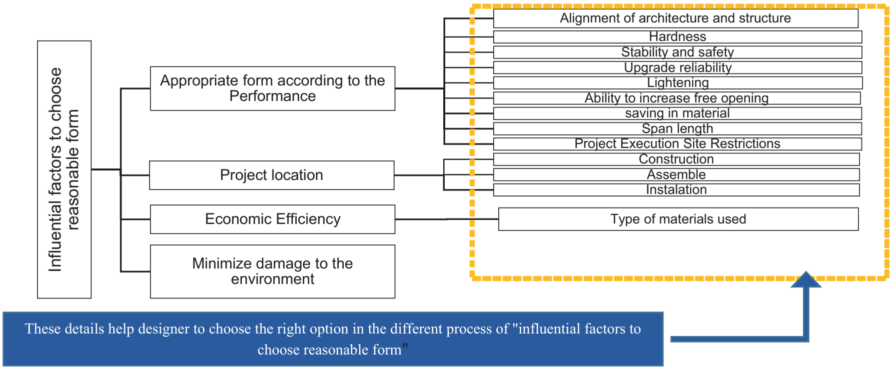

Fig. 3 Influential factors to choose an appropriate form

Selecting general shape options: proper form, project location, economic savings, and minimal environmental damage will all affect the choice of options. Each of them is affected by the items shown in Fig. 3.

The report containing the studies of this stage should show the logic and the way of choosing the studied options and the criteria and the way of choosing the superior option by presenting convincing arguments. If the competent authority confirms the quality, quantity, and accuracy of the studies, from now on, the detailed design steps of the superior option will be followed.

(b) *To design the construction method:* The design of the construction method depends on the type of form and structure that is considered in the form selection stage. Construction engineers will suggest the best of the various manufacturing processes for the next design to the construction design team. The selection of the construction process and the design of the construction method are two different separate, but parallel processes. Therefore, it is necessary to emphasize that the structure design process is not only a process that cannot be separated from the practical measures of construction, assembling, and installation of the structure but also determines the step-by-step activities and methods of construction [10].

(c) *To design the texture and installation*: After selecting the type of texture and installation method, the design engineers draw the texture and installation method according to the proposed option and provide it to the construction engineers.

(d) *To design how to transport and transfer to the place:* Depending on what method is chosen for transporting the structure, the creativity and experience of design engineers in designing the transport method is very important. The weight of the built modules and the size of the parts will be depending on different texture and installation methods, and choosing the best and the most economical method in designing the method of transporting the structure will have a great impact on reducing costs and construction speed.

(e) *To design the maintenance method:* If at the beginning and at the time of designing the structure the maintenance methods of the building are considered and designed, this will reduce maintenance costs and reduce renovation during operation, as well as the life of the structure.

2.2 Construction of Spatial Structures

The manufacturing process includes the manufacture and preparation of components and connections, followed by their storage, transportation, and connection to each other based on detailed drawings of construction, assembling, and installation.

The construction process from component part to whole is shown in Fig. 4.

2.3 Assembling and Installation Process

Any special or supplementary requirements related to texture and installation for a particular structure must be clearly specified in the specifications of all projects. In the design process from the component to the whole stage of assembling and installation of a spatial structure, according to the specific limitations of each project, two methods are effective: (a) assembling method and installation in place and (b)

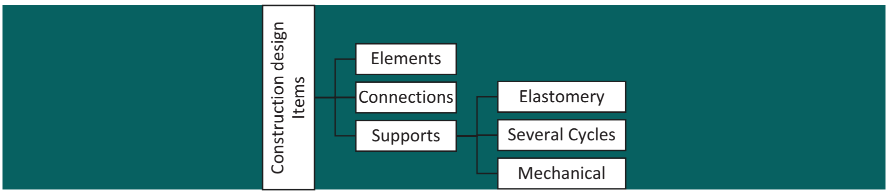

Fig. 4 Construction design items

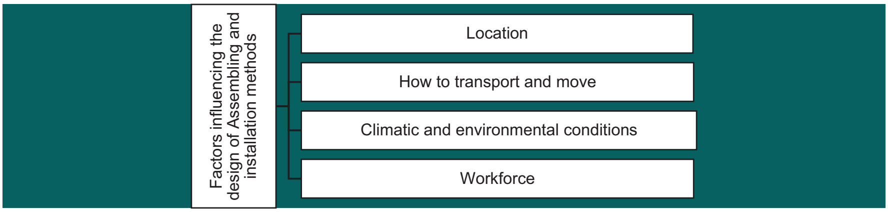

Fig. 5 Factors influencing the design of assembling and installation methods

weaving method and installation on the ground. Normally, due to environmental conditions such as wind and especially temperature and careful selection of the position of the structure in the final adjustment stage, the faults are decreased as much as possible. Figure 5 shows factors influencing the design of assembling and installation methods.

2.4 Maintaining and Repairing Operation Period

Building operation and use is one of the most critical aspects of high-performance buildings, but operation and maintenance (O & M) information is often not communicated effectively to the design and construction team. Operating expenses represent over 95 percent of building life cycle costs, yet operations and maintenance personnel are usually the last to be consulted during programming and design. In order to manage the integrated design of spatial structures, the Design-Build-Operate-Maintain (DBOM) making a contract between the operations and maintenance staff and the owner would have an improvement impact on high-performance results [11].

3 Results and Discussion

According to the investigation done, an integrated management diagram to optimize energy consumption and to address positive buildings is presented. This diagram is designed around a systematic axis, and it manages the optimal time, cost, and energy while considering the sustainability to develop a decision model and to strategically adopt spatial structure as prefabricated and engineered systems in the design and construction planning of green facilities. The diagram is divided into four stages:

Step 1—Metric determination for positive design
Step 2—Integrate axiomatic design and detailing
Step 3—Integrate design knowledge and environmental impact to develop the concept considering climatic potential
Step 4—Result verification by using software tools

Step 1: Metric determination for positive design

The first step provides the correlation between the basic requirements (customer needs) and the technical requirements. The requirements of the employer are examined at the same time as the technical requirements provided by the design and construction team. Then the performance requirements including optimization and initial data to improve the positive performance of buildings are at the highest level of this process. The output of this step will be to identify the basic needs, which includes design requirements and limitations and functional and unfunctional potentials of the design (Fig. 6).

Step 2: Integrate axiomatic design and environmental impact

According to the functional needs, the design parameters are considered by IBD team; at this stage, the process of designing spatial structures is begun, and the parameters show how and with what tools the functional needs of each part can be met. The goal is to meet all the functional requirements to meet the basic need. According to the most important functional needs, the graph grows the parameters are developed. The result of this step will be the primitive concept of building, which details are related to the type of structure, type of assembling, type of carrying, and initial form with climatic characteristics (Fig. 7) (Table 1).

Step 3: Integrate design knowledge and environmental impact to regenerative design

Addressing the regenerative design principles framework, especially at this stage, is necessary, to reduce energy consumption and decrease environmental impact. After categorizing the targeted parameters by the IBD team, this information will be presented to the design team. All three categories of the design process, Architecture, Structure, and Mechanical, must be done in parallel.

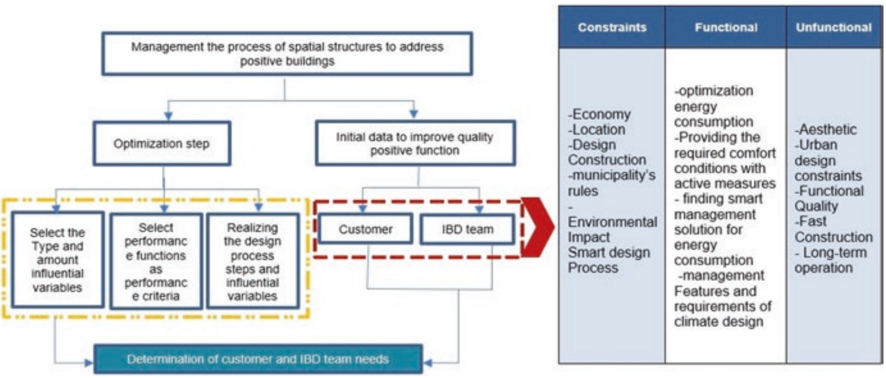

Fig. 6 Determination metrics

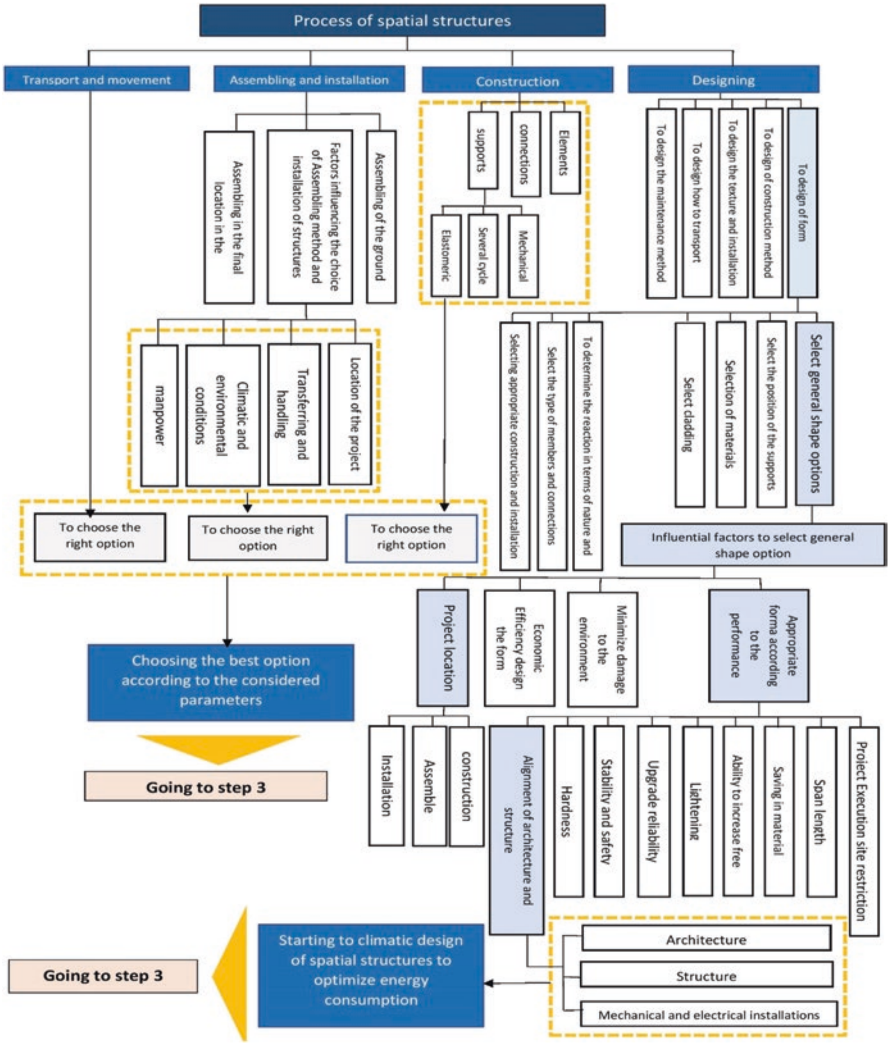

Fig. 7 Step 2 (integrate design and detailing)

In fact, this process is reciprocal, and after each step, the results of the three design groups are reviewed and, if necessary, changes are applied according to the goals (Fig. 8).

Step 4: Verification of result

To validate the result at this stage, the designer team must check all consequences of the impact on the environment and energy consumption again.

Table 1 Requirements and parameters

Functional requirements	Optimization energy consumption	Providing the required comfort conditions with active measures	Finding smart management solution for energy consumption	Management features and requirements of climate design
Parameters	Realizing the design steps and influential variables in different spatial structures process	Alignment architecture and structure Appropriate form according to the performance	Mechanical and electrical system New energy resources	Appropriate materials, alignment architecture and structure, hardness, stability and safety, upgrade reliability, lightening, ability to increase free opening, saving in material, span length

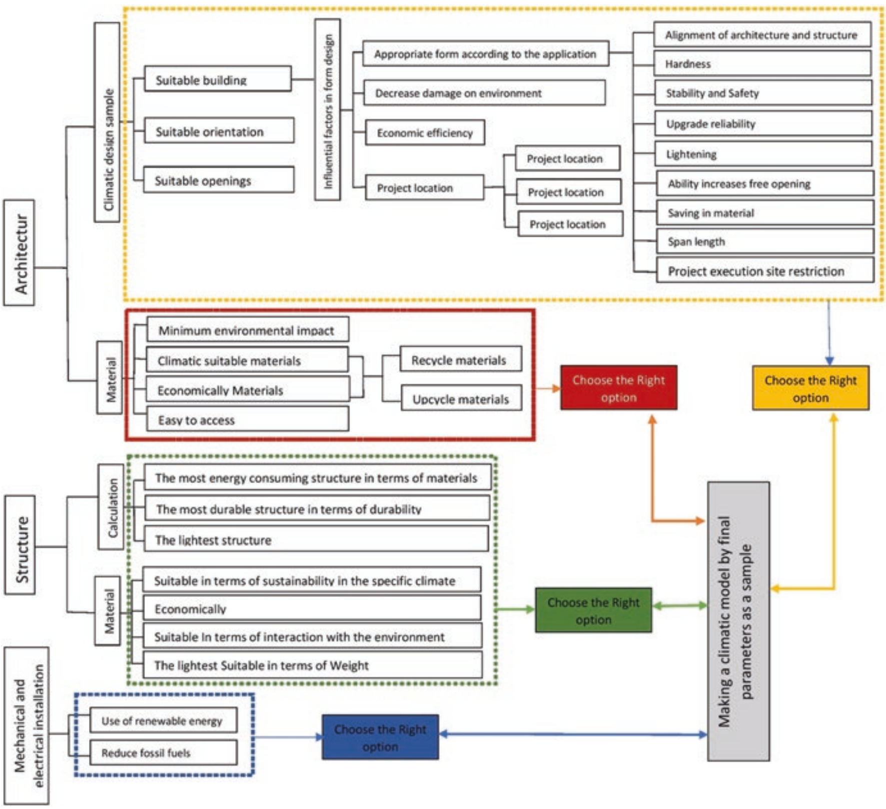

Fig. 8 Step 3 (integrate design knowledge and environmental impact)

4 Conclusion

Since achieving a basic model of positive buildings required enough knowledge about all stages and effective parameters in different processes of spatial structures, in addition, the existence of a management potential is necessary to direct all parts at the same time in order to eliminate mistakes and not wasting time. This process management of spatial structures is the necessary way to address positive buildings. The knowledge of management can lead all stages of a design to the goals of sustainability, by reducing the environmental impact in different views and aspects. This article presented all details, important parameters in different processes, processes that must be done simultaneously, and interdependent processes, along with a sample of tables including basic needs and effective parameters to meet those needs.

Due to the various factors involved in the structural design part, and the multiplicity of influential parameters, here authors have considered materials as one of the most important common parts between structure and architecture, but to achieve more realistic results, it is important to consider the connections, the type of spatial structure, the substructures for claddings on the amount of energy consumption and environmental impact.

Since the purpose of this paper, in an overview, is to create an integration process and show how the different parts of a spatial structure's process are performed in parallel, no further details are provided here, but it can be an issue for the future research to fill the existing knowledge gap about these structures.

References

1. Ikudayisi, A., Chan, A., Darko, A., & Adegun, O. (2022). Integrated design process of green building projects: A review towards assessment metrics and conceptual framework. *Journal of Building Engineering, 50*(June), 104180. https://doi.org/10.1016/J.JOBE.2022.104180
2. Javanmard, Z., & Nasser Alavi, S. (2017). *Cladding design of spatial structures in the direction of sustainable architecture*. 2th International conference on modern researches in applied sciences and engineering science.
3. United Nations Environment Programme. (2020). *Global status report for buildings and construction: Towards a zero-emissions*, Efficient and Resilient Buildings and Construction Sector.
4. Yang, X., Hu, M., Zhang, C., & Steubing, B. (2022). Key strategies for decarbonizing the residential building stock: Results from a Spatiotemporal Model for Leiden, The Netherlands. *Resources, Conservation and Recycling, 184*(September), 106388.
5. Fitria, D. (2021). The importance of iterative process in facade design optimization for a green office building in South Tangerang City. *IOP Conference Series: Earth and Environmental Science, 907*(1). https://doi.org/10.1088/1755-1315/907/1/012013
6. Horman, M., & Riley, D. (2006). Delivering green buildings: Process improvements for sustainable construction. *Journal of Green Building, 1*(1), 123–140. https://doi.org/10.3992/JGB.1.1.123
7. Feng, K., Lu, W., & Wang, Y. (2019). Assessing environmental performance in early building design stage: An integrated parametric design and machine learning method. *Sustainable Cities and Society, 50*(October), 101596. https://doi.org/10.1016/J.SCS.2019.101596

8. Lapinskienė, V., & Motuzienė, V. (2021). Integrated building design technology based on quality function deployment and axiomatic design methods: A case study. *Sustainable Cities and Society, 65*(February) https://doi.org/10.1016/J.SCS.2020.102631
9. Blismas, N., Pasquire, C., & Gibb, A. (2006). Benefit evaluation for off-site production in construction. *Construction Management and Economics, 24*(2), 121–130.
10. President's Office of Strategic Planning and Supervision. (2019). *Regulations for astronaut structures*, Publication 400.
11. Jiang, C., Tang, C., Seidel, & Wonka, P. (2017). Design and volume optimization of spatial structures. *ACM Transactions on Graphics (TOG), 36*(4), 1–1.

Assessing Environmental Performance and Climate Change Mitigation Effects of Bio-based Materials for Building Retrofitting

Letizia Dipasquale and Riccardo Maria Pulselli

1 Introduction

Building retrofitting processes will play a key role in achieving the goal of a climate-neutral EU by 2050 [1]. Nowadays, around 75% of the building stock in the European Union (EU) is energy-inefficient [1, 2]. Having estimated that more than 85% of today's buildings are likely to still be in use in 2050, it is evident that accelerating the retrofitting processes of existing buildings is crucial to reduce fossil fuels consumption and CO_2 production in the building sector [1–7]. Appropriate improvement of existing buildings not only allows to reduce emissions in the use phase of buildings life cycle but also helps to extending their life span, reducing the demand for new construction, and thus implementing virtuous processes of circular economy [1, 8].

Much effort has been made in recent years to improve the energy performance of buildings, considering the operational phase as the most impacting of a building life cycle [3, 5, 9]. However, retrofitting processes also require materials and produce greenhouse gas emissions. The most common energy-efficient measure is thermal insulation, besides the replacement of fossil heating systems. Conventional materials often require energy-intensive industrial processes for production such as mineral wools and foams from petroleum chemistry (polyurethane foam, expanded polystyrene, or extruded polystyrene) [9]. In a perspective of minimizing impacts of retrofit, increasingly attention should be given to reduce the embodied energy, i.e., the energy used in building materials during the processes of production, on-site construction, and final demolition.

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In order to reduce energy and resource consumption in retrofitting processes, bio-based materials are a promising solution [10–12], as they are widely available as part of the biosphere (e.g., timber, straw, hemp, cork, clay, and earth); they have a low energy requirement for their processing, and most of them exploit biological wastes and agricultural by-products following principles of circular economy. Moreover, plant-based materials are capable of storing carbon, meaning that as they grow, they absorb carbon dioxide and store it by fixing carbon into biomass.

Natural and bio-based materials have been used for centuries in vernacular architecture, but in the last decades, many of them have been increasingly used in the building sector, both in new constructions and in renovation, due to their good environmental performance [13–15]. Several studies published in recent years have highlighted the thermal, hygro-thermal, and acoustic performance of such materials [14–17] and their contribution to improved indoor air quality. Materials such as cork, hemp, and straw are highly insulative and can be used in a variety of applications, including dry construction. Others like earth and clay have good thermal inertia so that the combinations of natural fibers and natural binders, such as earth or lime, give rise to bio-based products with excellent thermos-hygrometric performances [18]. In the case of historic buildings that use traditional materials, such as stone, brick, lime, and wood, the use of bio-based materials appears particularly appropriate, as the physical, hygroscopic, and mechanical characteristics are in general more similar and therefore compatible with those of the existing building materials [19–21].

2 Materials and Methods

2.1 Description of the Case Study

In this paper, we report the results of an environmental assessment of the retrofit of a rural dwelling that relies on the large use of bio-based materials. The building chosen as a case study is an example of rural architecture in central Italy, located south of Florence in Tuscany. As most of historical rural buildings in the area, the walls were originally made of stone ashlars mixed with brick, bound with lime mortar and covered with lime-based plaster mixed with natural pigments often obtained from local earths. Timber was employed for the structural elements of floors and roofs, as well as door and window fixtures. The building, which originally served as a barn, has been transformed into a residential building after a renovation in the mid-twentieth century. This intervention led to a profound transformation of the physical, thermo-hygrometric, and structural behavior of the building. In fact, the lime plasters that guaranteed the transpiration and hygroscopicity of the masonry were replaced by cement plasters; reinforced brick concrete slabs were introduced in place of the lightweight wooden slabs that guaranteed an elastic behavior of the building.

The renovation and energy retrofit project, carried out in 2020 by the architectural studio Officina Abitare, followed an integrated design approach that involved the improvement of the performance of the envelope, structural consolidation, remodeling of interior spaces, modifications to openings to improve natural lighting, and a complete replacement of the heating and cooling system.

The floor plan configuration has remained almost unchanged, with minor modifications to optimize the distribution and the introduction of a technical room on the ground floor. The kerosene heating system has been replaced by a heat pump for air-conditioning and DHW. Masonry and horizontal structures were consolidated, resulting in improved seismic building behavior. The surface area of the openings on the main, north-facing façade was increased and the old window frames have been replaced with single-sash natural wooden windows in order to increase the free supply of natural lighting [22].

The materials chosen for both the insulation and the interior finishes are bio-based. The external walls were insulated using two panels of reed for a total thickness of 8 cm, combined with a 3 cm layer of hemp and lime thermal plaster, which was applied both on the outer and inner side of the wall. The attic was insulated with a sheep's wool mattress, while the ground floor and part of the roof was insulated with wood fiberboards. Natural materials were also chosen for the interior finishes. The floors are paved with local wood and handmade terracotta elements arranged with a contemporary laying; external doorsills are made of local pietra serena. The use of lime and hemp plasters for the internal walls, thanks to their good hygroscopic behavior, has a positive influence on indoor air quality.

Table 1 and Figs. 1 and 2 describe and represent the main interventions of the retrofitting activity. The environmental profile of this intervention was compared with a hypothetical retrofitting scenario with synthetic materials, adopting the Life Cycle Assessment (LCA) methodological framework.

2.2 Qualitative Observations on the Sustainability of the Retrofit Intervention

The materials and techniques used in the refurbishment of the case study building have been carefully selected from a sustainable integrated design perspective aimed at contributing to the well-being of the inhabitants, while respecting the environmental context and the identity of the historical building.

The materials and systems adopted in the renovation, which are mostly of natural origin, are characterized by greater compatibility in physical, chemical, mechanical, and material terms with the historical building than conventional insulation and finishing materials [10, 15, 17, 20]. Breathable and hygroscopic lime and hemp plasters can regulate excess indoor humidity and ensure good indoor air quality [21]. Air quality is also guaranteed by the absence of indoor pollutants in all materials used for the finishes.

Table 1 Characteristics of the building studied as a case study before and after the intervention

Basic description of the case study		Retrofit solutions adopted	
Location and context of the building	Italy, Florence, rural area	**Walls insulation**	Reed panels + lime and hemp thermal mortar
Walls structure	Stone and brick masonry	**Roof insulation**	Sheep wool mats
Slabs construction	Reinforced brick concrete	**Slabs**	Timber structure
Insulation	Absent	**Ground floor insulation**	Wood fiber panels + ventilation
Wall finishes	Cement plaster	**Wall finishes**	Lime and hemp plaster
Paving materials	Terracotta	**Paving**	Wood, stone, and terracotta
Heating system	Kerosene heating system	**Heating and cooling system + hot water production**	Heat pump system
Windows construction	Single glazing, wooden frame	**Windows construction**	Double glazing, wooden frame
		Seismic retrofit	Reinforcement of masonry and floors with steel beams
Energy efficiency classes	G	**Energy efficiency classes**	A3

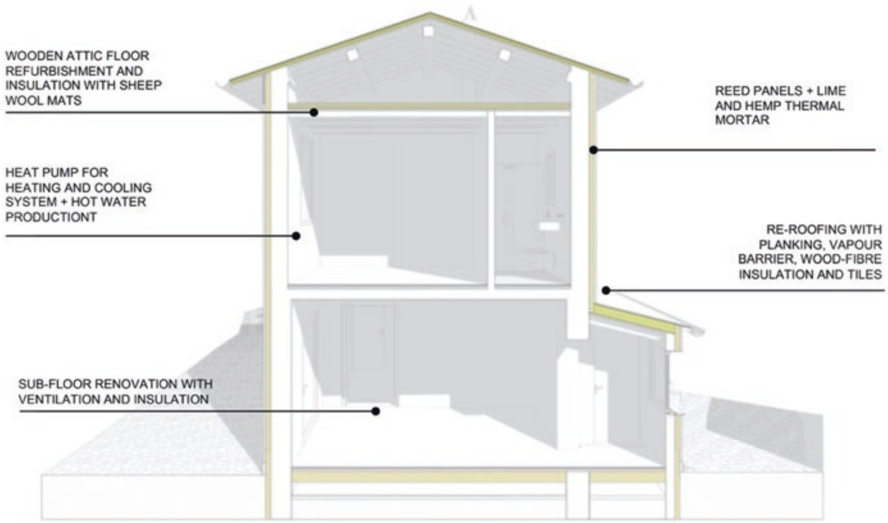

Fig. 1 Building sketch with renovated components marked in yellow. (Credits: Officina Abitare)

Fig. 2 Building views from left to right: outdoor view, indoor view, detail of reed panels insulation (© Matteo Pierattini)

The choice of reed panels as external insulation is due not only to their low environmental impact but also to obtain a rough texture of the facade such as the handcrafted finishes. The irregular surface—that cannot be obtained by applying rigid panels—in addition to respecting the identity character of Tuscan rural buildings can also have an advantage in terms of reducing the absorption of solar radiation [22].

Hemp is a raw material that has found wide acceptance in the construction industry in recent years, thanks to its rapid growth and the limited amount of fertilizer, water, and energy required in the cultivation phase of the crop. Lime and hemp mortar has excellent performance in terms of environmental comfort [13, 15, 18]; in fact it has excellent insulating power, both thermally and acoustically; it is permeable to water vapor, reducing the risk of condensation; it is fire, frost, and rodent resistant. Also, the properties of the reed are suitable for obtaining excellent thermal performance, with a low economic and environmental impact, thanks to the ability of the raw material to grow quickly and reproduce easily [6]. Furthermore, the use of local and natural materials promotes socioeconomic sustainability as it implements the development of a local supply chain, enhances the value of raw materials and craftsmanship linked to the local area, and reduces transport costs.

2.3 *Quantitative Environmental Assessment*

Besides qualitative observations, the present study aims at quantitatively evaluating the sustainability of solutions for building retrofitting considering bio-based and natural materials as main components, compared to standard constructive materials.

The compared analysis is based on the Life Cycle Assessment considering the material mass and material emission factors. Most of the emission factors are taken from Ecoinvent 3.6 (CML-IA method, GWP100 impact category), and in the case of innovative materials, from published EPD of bio-based and natural materials (i.e., hemp fiber [23] and reef [24]; the latter is assumed similar to straw). Contextually, the carbon storage in biomass has been assessed based on values provided by producers in the published EPD [23, 24]. Moreover, values for reef are coherent with assessments made for bamboo [25].

In particular, three scenarios have been compared: the standard scenarios with standard gypsum and cement based plasters and EPS as insulation; the bio-composite scenario with hemp and lime plasters and hemp and lime blocks for insulation; the actual scenario (case study building) with hemp and lime plasters and reed panels for insulation. The three wall sections are shown in Fig. 3 with proper thicknesses in order to achieve the same level of transmittance ($U \simeq 0.34$ W/m^{2}K) for the three walls and make them comparable in terms of thermal/energy performance.

3 Results and Discussion

The compared analysis concerns the assessment of both the carbon footprint (CF: emitted kgCO_2eq) and the carbon storage (absorbed kgCO_2) per each material. The following tables show the total volume of material used for retrofitting by referring to a total surface of external walls of 162.4 m^2 and internal walls of 120 m^2.

Table 2 shows results for the standard scenario. The total impact in terms of greenhouse gas emission is 19.3 t CO_2eq (corresponding to a mass of 18.0 t of materials used). There is not any carbon uptake directly associated to these materials.

Table 3 shows results for the second scenario. The total impact in terms of greenhouse gas emission is 10.6 t CO_2eq, i.e. – 45% compared to the standard scenario (corresponding to a mass of 12.3 t of materials used, i.e. −31%). The carbon uptake directly associated to these materials is 3.4 t CO_2 compensating around 32% of the impact of the construction.

Table 4 shows results for the natural scenario. The total impact in terms of greenhouse gas emission is 2.9 t CO_2eq, i.e., 85% compared to the standard scenario (corresponding to a mass of 9.5 t of materials used, i.e., 47%). The carbon uptake directly associated to these materials is 5.8 t CO_2 compensating almost twice the impact of the construction.

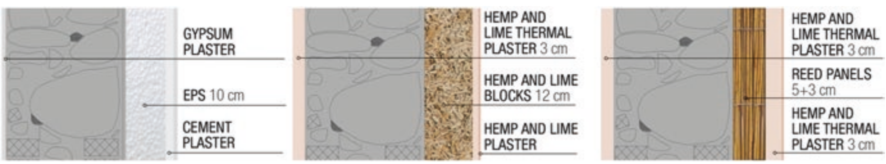

Fig. 3 Wall section and thicknesses of three compared scenarios ($U \simeq 0.34$ W/m^{2}K)

Table 2 LCA (simplified) of the standard scenario (EPD insulation) of building retrofitting

Scenario standard	Thickness	Volume	Density	Mass	EF	CF	C storage	C uptake
Item	m	m^3	kg/m^3	kg	$kgCO_2eq$/kg	$kgCO_2eq$	$kgCO_2$/kg	$kgCO_2$
Gypsum plaster	0.01	1.2	1200.00	1440	0.58	831	_	_
Existing wall								
Cement mortar	0.015	2.436	2200.00	5359	1.02	5488	_	_
EPS panels	0.09	14.616	30.00	438	4.21	1847	_	_
Glassfiber net	_	_	0.15	24	2.60	63	_	_
Cement plaster	0.03	4.872	2200.00	10,718	1.02	10,976	_	_
Paint	_	_	_	25	2.09	52	_	_
Total				18,005		**19,258**		

Table 3 LCA (simplified) of the bio-composite scenario (hemp insulation) of building retrofitting

Scenario Hemp based	Thickness	Volume	Density	Mass	EF	CF	C storage	C uptake
Item	m	m^3	kg/m^3	kg	$kgCO_2eq$/kg	$kgCO_2eq$	$kgCO_2$/kg	$kgCO_2$
Hemp-based thermal plaster	0.03	3.6	400.00	1440	0.62	897	−0.28	−396
Existing wall								
Hemp-based mortar	0.015	2.436	1100.00	2680	0.62	1669	−0.10	−268
Hemp lime blocks	0.12	19.488	300.00	5846	0.62	3641	−0.37	−2144
Hemp-based thermal plaster	0.03	4.872	300.00	1462	2.60	3800	−0.37	−536
Hemp-based plaster	0.005	0.812	1100.00	893	0.62	556	−0.10	−89
Paint	_	_	_	25	0.00	0		
Total				12,346		**10,564**		**−3433**

Figure 4 shows the comparison of the three scenarios by referring to three assessed values of material mass, carbon footprint, and carbon storage. The mass of material generally decreases, thanks to the introduction of hemp biomass in bio-based materials and particularly in the third scenario with reed panels. Values of carbon footprint show larger variations depending on both the mass of material used and the emission factors of natural materials. These are generally lower compared to cement-based or synthetic materials thanks to more sustainable production chain processes, mostly deriving from agriculture instead of intensive energy industrial processes. Nevertheless, some contradictions can be also highlighted; for example, it can be observed that the impact of EPS (1.8 t CO^2eq) is lower than hemp blocks

Table 4 LCA (simplified) of the natural scenario adopted (reed insulation) of building retrofitting

Scenario reed based	Thickness	Volume	Density	Mass	EF	CF	C storage	C uptake
Item	m	m^3	kg/m^3	kg	$kgCO_2eq/kg$	$kgCO_2eq$	$kgCO_2/kg$	$kgCO_2$
Hemp-based thermal plaster	0.03	3.6	400.00	1440	0.62	897	−0.28	−396
Existing wall								
Hemp-based mortar	0.015	2.436	1100.00	2680	0.00	0	−0.10	−268
Natural reed panel	0.08	12.992	190.00	2468	0.10	254	−1.83	−4526
Hemp-based thermal plaster	0.03	4.872	400.00	1949	0.62	1214	−0.28	−536
Hemp-based plaster	0.005	0.812	1100.00	893	0.62	556	−0.10	−89
Paint	_	_	_	25	0.00	0		
Total				9455		**2921**		**−5815**

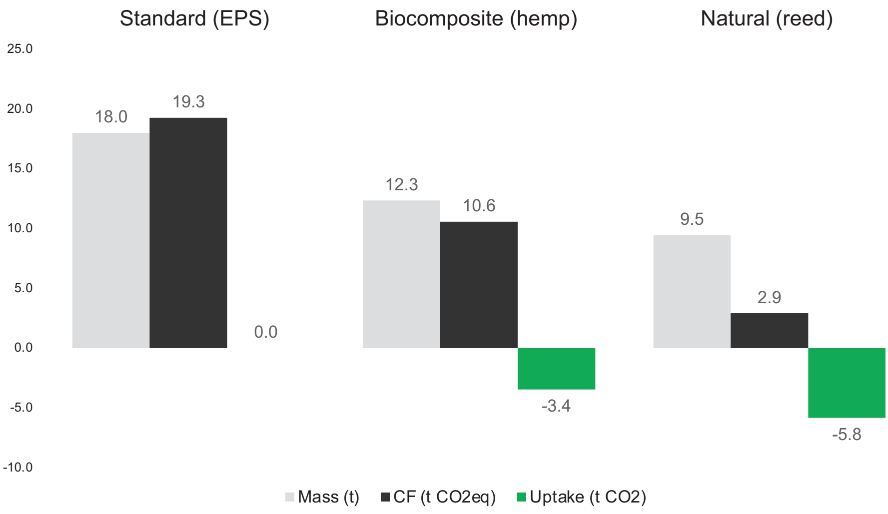

Fig. 4 Compared analysis of retrofitting scenarios based on material mass, carbon footprint (CF), and carbon uptake

(3.6 t CO_2eq) due to the mass of material used (i.e., low density of EPD). Results are always determined by a combination of the two parameters, material density and material emission factor.

The additional benefit of natural materials consists in their capacity to storage carbon as the result of CO_2 absorption and biomass growing during plant growth. Assuming that the carbon storage persists at least 100 years as estimated lifetime to be considered an almost permanent stock, the bio-based material structure compensates almost one-third of its impact and the natural scenario can be classified as theoretically carbon neutral being absorption higher than emission.

4 Conclusion

The paper describes an innovative action of retrofitting of a typical rural house in Tuscany, central Italy. Instead of energy-intensive industrial materials, such as cement mortars and plasters and EPD for insulation, the architects (Officina Abitare firm) have chosen bio-based and natural materials, especially hemp-based plasters (with thermal performance) and reed panels for insulation.

From the qualitative point of view, the retrofit measures follow an integrated sustainable design approach that take into account building specific characteristics, aiming at matching the needs of the inhabitants while respecting the identity of the building and limiting the impact on human health and environment. The use of natural materials allows for good insulation of the building, while ensuring good air quality and compatibility with the physical, chemical, mechanical, and material characteristics of the historic building.

A simplified LCA has been developed for a quantitative assessment. Through a compared analysis of three scenarios with the same energy performance—standard, hemp and lime based, and reed based (implemented in the building)—results show better environmental performances of bio-based and natural materials in terms of reduced carbon footprint. Moreover, values of carbon uptake have been assessed considering that natural materials can be eventually interpreted as carbon stocks, assuming they will remain embedded in the building structure for at least 100 years. This allows for offsetting one-third of the carbon footprint in the case of the bio-composite scenario (hemp based) and the total emission in the case of the natural scenario (reed based); the latter could be considered theoretically carbon neutral.

Bio-based materials are profitable solutions for building retrofit, as these materials offer good thermal performances and other benefits, reduced levels of embodied energy, and lower climate impact compared to conventional materials. Nevertheless, they are still underused due to a lack of knowledge of the construction industry and regulators and more information from research, especially extended to the lifecycle processes, is needed to evaluate their environmental performances and build trust of technical end users and investors. The life-cycle approach is useful for understanding the possible consequences of decisions taken during the design process, evaluating the best solutions from an environmental impact perspective.

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References

1. European Commission. (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. COM(2020) 662.
2. UNEP- Global Alliance for building and construction. (2021). *Global status report for buildings and construction*. UN Environment Programme.
3. Lidelöw, S., Örn, T., Luciani, A., & Rizzo, A. (2019). Energy-efficiency measures for heritage buildings: A literature review. *Sustainable Cities and Society, 45*, 231–242.
4. Claude, S., Ginestet, S., & Altamirano, H. (2019). Evaluating retrofit options in a historical city center: Relevance of bio-based insulation and the need to consider complex urban form in decision-making. *Energy and Buildings, 182*(2019), 196–204.
5. Amini Toosi, H., Lavagna, M., Leonforte, F., Del Pero, C., & Aste, N. (2020). Life cycle sustainability assessment in building energy retrofitting; a review. *Sustainable Cities and Society, 60*, 102248.
6. Asdrubali, F., Bianchi, F., Cotana, F., D'Alessandro, F., Pertosa, M., Pisello, A. L., & Schiavoni, S. (2016). Experimental thermo-acoustic characterization of innovative common reed bio-based panels for building envelope. *Building and Environment, 102*(2016), 217–229.
7. Pittau, F., Lumia, G., Heeren, N. G., & Iannaccone, G. H. (2019). Retrofit as a carbon sink: The carbon storage potentials of the EU housing stock. *Journal of Cleaner Production, 214*, 365–376.
8. European Environmental Agency. (2022). *Modelling the renovation of buildings in Europe from a circular economy and climate perspective*, in https://www.eea.europa.eu/publications/building-renovation-where-circular-economy/modelling-the-renovation-of-buildings/view
9. Cabeza, L. F., Barreneche, C., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E., & Fernandez, A. I. (2013). Low carbon and low embodied energy materials in buildings: A review. *Renewable & Sustainable Energy Reviews, 23*, 536–542.
10. Claude, S., Ginestet, S., Bonhomme, M., & Escadeillas, G. (2020). Performance of bio-based insulation materials in an old building envelope system. In F. Pacheco-Torgal, V. Ivanov, & D. C. W. Tsang (Eds.), *Woodhead Publishing Series in civil and structural engineering, bio-based materials and biotechnologies for eco-efficient construction* (pp. 105–128). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-819481-2.00006-4
11. Torres-Rivas, A., Palumbo, M. L., Haddad, A. N., Cabeza, L. F., Jiménez, L., & Boer, D. (2018). Multi-objective optimisation of bio-based thermal insulation materials in building envelopes considering condensation risk. *Applied Energy, 224*(2018), 602–614.
12. Mileto, C., Vegas, F., Llatas, C., & Soust-Verdaguer, B. (2021). A sustainable approach for the refurbishment process of vernacular heritage: The Sesga House case study (Valencia, Spain). *Sustainability, 13*, 9800. https://doi.org/10.3390/su13179800
13. Agliata, R., Marino, A., Mollo, L., & Pariso, P. (2020). Historic building energy audit and retrofit simulation with Hemp-Lime Plaster—A case study. *Sustainability, 12*(11), 4620. https://doi.org/10.3390/su12114620
14. Bottino-Leone, D., Larcher, M., Sabbadini, S., Herrera-Avellanosa, D., Haas, F., & Troi, A. (2019). Evaluation of natural-based internal insulation systems in historic buildings through a holistic approach. *Energy, 181*, 521–531.
15. Walker, R., & Pavía, S. (2015). Thermal performance of a selection of insulation materials suitable for historic buildings. *Building and Environment, 94*, 155–165.
16. Galimshina, A., Moustapha, M., Hollberg, A., Padey, P., Lasvaux, S., Sudret, B., & Habert, G. (2022). Bio-based materials as a robust solution for building renovation: A case study. *Applied Energy., 316*, 119102.
17. Dotelli, G. S., & Melià, P. (2019). An LCA case study of vernacular architecture retrofitting in northern Italy with natural and bio-based materials. In M. Sonebi & S. Amziane (Eds.), *Proceedings of 3rd international conference on bio-based building materials ICBBM 2019* (pp. 737–738).

18. Kymäläinen, H., & Sjöberg, A. M. (2008). Flax and hemp fibres as raw materials for thermal insulations. *Building and Environment, 43*, 1261–1269.
19. Ata-Ali, N., Penadés-Plà, V., Martínez-Muñoz, D., & Yepes, V. (2021). Recycled versus non-recycled insulation alternatives: LCA analysis for different climatic conditions in Spain. *Resources Conservation and Recycling, 175*, 105838.
20. Pineda, P., García-Martínez, A., & Castizo-Morales, D. (2017). Environmental and structural analysis of cement-based vs. natural material-based grouting mortars. Results from the assessment of strengthening works. *Construction and Building Materials, 138*, 528–547.
21. Kharwar, D., Saroj, A. K., Marwein, P., Paul, S., & Singh, H. (2021). A review paper on improving the Indoor Air Quality (IAQ) in green and conventional buildings using sustainable materials. *JETIR, 8*(4), 27–31.
22. Officina Abitare. (2022). Casa Rosa. *Azero, 30*, 75–81.
23. EPD ISO14025. (2020). *KOBE-CZ hemp fiber insulation*. The International EPD® System, www.environdec.com
24. EPD ISO14025. (2022). *Straw as insulation material- UK*. The International EPD® System, www.environdec.com
25. Neri, E., Esposito, G., Marchi, M., Niccolucci, V., Pulselli, F. M., Marchettini, N., Lajo, M., Rissone, E., & Pulselli, R. M. (2022). *Analisi del ciclo di vita e CO2 assorbita da un bambuseto gestito in Italia: applicazione ad un caso studio*. XVI Convegno dell'Associazione Rete Italiana LCA. 22–24 Giugno 2022, Palermo.

Solar Architecture in Rome: The Refurbishment of Historic Buildings with Active Solar Technologies

Serena Baiani, Paola Altamura, Elena Lucchi, and Giada Romano

1 Introduction

The correlation of form with functionality has determined a slow evolution of Architecture toward contemporary typologies, in which the investigation of the relationship between structure and energy has identified two crucial conditions for the typological and the morphological development of architecture: firstly, the bioclimatic behaviors; secondly, the integration of building service systems [1]. Historical studies identify the sun position as a fundamental criterion to optimize the buildings' behavior. Consistently, architectural integration of building installations is an emerging design theme in the intervention on existing buildings, which, since the 1970s, is mainly oriented toward the use of renewable energy sources (RES). It also offers an innovative design condition enabling the development of efficient architectural morphologies. The context of Rome in Italy is particularly significant for studying the integration of solar energy in historic buildings. As matter of fact, energy efficiency is one of the central areas for reducing energy consumption and climate-altering emissions. European data show that 40% of energy consumption and 36% of emissions derive from consumption in buildings and 35% of buildings have more than 50 years with 75% of the building stock, which is inefficient from the energy point of view. The percentage values of the city of Rome can be

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superimposed on the European data, so the 2030 emissions reduction objectives must be centered on energy efficiency policies as well as on the redevelopment of the public and private building stock. Both policies should be referred to both new constructions and existing real estate. In particular, museums and historic buildings are a further object of an agreement signed in 2018 by the Italian Ministry of Culture and the ENEA Research Institute for energy savings, to define design projects for assessing their energy footprint, also identifying adequate energy efficiency measures aimed at reducing consumption for heating, ventilation, and air conditioning (HVAC) by up to 30% and cutting lighting consumption by up to 40%.

2 Aims and Methodology

A first map of historical architectures with integrated and nonintegrated active solar systems in Rome allowed a reconstruction of some evolutionary steps from technical and architectural point of views, focusing the attention on the criteria adopted specifically on historical buildings. The first selection identified five significant interventions for the integration of active energy systems in historic buildings, carried out in different periods and with different approaches (Fig. 1). These examples identify the recurring typological and morphological solutions, to better understand the criteria adopted in relation to the existing one, showing a careful and rigorous "energy refurbishment" operation that derives from the attention to the regulatory request to reduce consumption from nonrenewable sources, even on architectures of historical and cultural value. The detailed description of the solutions is supported by a critical evaluation, partly carried out with the Italian Heritage Authorities (HA). This analysis aimed at expanding the evaluation with further operational criteria derived from the literature. This process is part of a research path oriented toward the definition of internationally agreed criteria for the design of BIPV on heritage buildings [11], paying particular attention to the objective of climate neutrality.

3 Solar Architecture in Rome: Five Emblematic Case Studies

3.1 Museo Explora: The Children's Museum in Rome

The Museum is located in Borghetto Flaminio and has been active since 2001. The area of 8000 m^2 has been restructured and upgraded, thanks to the support of private and public companies. In 1998, when the municipal area was given in concession by the Municipality, the buildings were in a complete state of decay, but in two and a half years, the adaptation to the exhibition function was completed for maintaining the historical memory of the industrial façade. The museum consists of an exhibition pavilion, a kitchen dedicated to food education workshops, a green area with

Fig. 1 Map of Rome: location of the case studies. (Source: Authors' elaboration)

free access equipped with games and photographic exhibitions, a bookshop, shop, bar, restaurant, and a reserved parking area [2]. The element that has most influenced the design of the exhibition pavilion is certainly the light: natural light, governed by the skylight, the walls, and the PV brise-soleils; artificial light, that in the evening, through the large windows, shows the internal playful activity. Explora is the first architectural integration project of PV systems on an industrial archaeology building of cultural interest and it is the first example of BIPV in Italy. It has two PV systems: the first one was built in 2001 thanks to the Research Project *"INNOPEX: Innovative architectural integration of photovoltaic energy in existing buildings*" [3]. A BIPV system is installed on the skylight and on the south side of the pavilion. It is composed of 12 mobile canopies that allow for variations in the shading of the façade according to the seasons. There are 180 panels installed, 72 on the skylight and 108 on the side canopies. PV modules have been designed specifically for the transparent elements of the roof and for the mobile shading of the south façade. It is therefore a multifunctional system, with semitransparent BIPV, very innovative for its time. This system produces 15.2 kWp: the energy necessary to operate all the computers in the museum, many games, and exhibits. The second ground mounted

Fig. 2 BIPV brise-soleils and PV car shelter of the Explora Museum. (Source: Elena Lucchi)

PV was built in 2007 on the car park thanks to the GSE Energy Account. It is composed of 100 PV panels that cover the consumption of the offices and shops for a total production of 18 kWp. The PV shelter is a simpler and more traditional example; it is however not visible from the street and has a high solar potential. To maximize the electricity produced, it has been preferred to use traditional BIPV systems. The production data of the two plants is always visible, thanks to a constant and online monitoring system (Fig. 2).

3.2 Città dell'Altra Economia at the Former Slaughterhouse of Rome

The architectural project has a unique integration between cultural, social, and commercial activities (organic farming, fair trade, ethical finance, renewable energy, open communication, reuse, and recycling). The architectural project integrates restoration, addition, structural rehabilitation, eco-efficiency, and conservation of historical and new signs, in the optics of the unitary redefinition of an already stratified context. The functional program covers the gap between the porch and the canopies with a new steel structure that transforms the existing canopies and the intermediate void into a useful surface. The new envelope is divided into several "building modules" with maximum flexibility, alternating new spaces with open or covered spaces, to distinguish the original sections from the complex ones. The design project of Luciano Cupelloni lasted from 2004 to 2007, after surveys, investigations on the structures, tests on materials, and archaeological essays. It implemented an accurate conservative restoration of the main building and the adjacent portico and a specific rehabilitation of the iron and cast-iron structures [4]. The new volumes are made with an anti-seismic steel structure, entirely prefabricated for the benefit of performance and assembly. The new structures are independent from the old ones and technically reversible (Fig. 3).

The unique set of old canopies and new volumes is enclosed by a largely glazed envelope, which ensures maximum transparency to originally open structures. Glazed fronts and skylights led to an accurate control of the thermal behavior, starting from obviously non-modifiable orientation and position conditions. The control of the sun/air impact made it possible to maximize the solar thermal gains during the cold season and to minimize the incident solar radiation in the hot season. The

Fig. 3 Main building, canopies, and PV roof. (Source: [5])

long-glazed front, to the southeast, is protected by horizontal slats arranged in the lower part of the façade that integrate the effect of the existing canopy, ensuring transparency and a view toward the outside. The opening system of the new roof is an integrated technological solution that ensures natural zenith lighting, avoiding summer overheating, and which allows the correct arrangement of the PV panels, ensuring diffused light from the north and natural ventilation. The glass openings of the north-west sheds are shielded by vertical partitions and horizontal protrusions, to contain overheating in the hours of maximum impact of the early summer afternoon. The sheds are flanked by large flat skylights, shielded by two perforated stainless-steel plates in such a way as to allow diffused radiation and, only in winter, direct solar radiation. The protection of the glazed front from direct solar radiation was combined with the analysis of the natural aerodynamic flows induced by the front openings, arranged in the shaded area of the façade as opposed to those of the sheds, to favor summer cooling and air replacement. The optimization of thermal effects and natural lighting involved the use of stratified insulating glass, low emissivity with neutral reflection, on extruded aluminum profiles with thermal break, with motorized protruding doors. In order to reduce dispersions, high-performance hemp panels have been used combined with composite panels in aluminum and mineral core, for the ventilated façades, and with OSB panels on flat roofs and pitched roofs. A PV system consisting of 166 lead-free polycrystalline silicon panels, equal to 180 Wp per 30 kWp, ensures an annual production of about 40,000 kWh, which reduces CO_2 emissions by over 25,000 kg/year.

3.3 Sala Nervi, Aula Paolo VI: The Hall for Pontifical Audiences in the Vatican City

The building was designed by Pier Luigi Nervi in 1964 as a thermal-tight building with a trapezoidal plan adjacent to the Vatican Walls. The structure is composed of 4800 prefabricated reinforced concrete panels on the roof surface, supported by special iron trestles with shading functions. These elements were coupled to “V” and arranged along longitudinal bands and are half facing south and half facing north. The shielding function of the approximately 5000 m^2 of sunshade tiles arranged on metal supports with a triangular section connected on two cylindrical bases allows an approximate estimate to calculate the primary energy saved in terms

Fig. 4 BIPV roof of the Nervi Hall. (Source: Elena Lucchi and [6])

of summer cooling of the classroom below in approximately 8 tons of oil equivalent per year. The building naturally preserves an optimal temperature with great energy savings and guarantees a pleasant space with high thermal inertia. Forty years after its construction, the concrete panels have begun to deteriorate for the effects of urban pollution, thermal, and meteorological variations. This requires an accurate and onerous restoration, involving also the total replacement. Given the orientation favorable to solar radiation of the building, the Governorate of the Vatican decided to transform passive shading elements into active systems, also preserving the original appearance, and undertaking its eco-compatible policy. The project was realized by Livio de Santoli in collaboration with the German company Solar World (Fig. 4).

The BIPV panels and their reflective aluminum "opposite" replaced the concrete tiles, also producing electrical energy. The first phase of the project consisted in the removal of all 4800 shading elements in reinforced concrete, replacing the half whose surface facing south with 2400 PV modules, and the other half, oriented toward north, with aluminum semi-reflective panels, to increase the production efficiency of the PV panels by increasing the intensity of the solar radiation effect on the PV modules. All this has been planned with considerable savings in materials because it used the existing supports to which only modifications have been made to make them self-propelled to allow the rotation of the diffuser panels for the necessary cleaning and maintenance operations. In a second phase of the project, the installation of the necessary number of inverters placed on the roof has been planned and carried out, to transform the direct current produced by the PV modules into alternating current and, therefore, through adequate wiring, allow its transfer to the electrical transformer substation, located in the basement of the Hall to also power the adjacent areas of the Vatican. The plant has a peak power of 221 KWh and annually produces 300,000 KWh avoiding the emission of approximately 225,000 KG of CO_2 into the atmosphere with a saving of 80 tons of oil equivalent per year. Thanks to the PV panels on the roof of the Aula Nervi and a second plant, 310 tons of carbon dioxide were saved in the first two years of activity and 442 thousand kWh of clean energy produced. Two years after the inauguration of the PV system on the roof of the Papal Audience Hall, the Vatican city can boast a solar trigeneration: the ability to generate three forms of secondary energy starting from the energy of the sun: electrical, thermal, and cooling. The latest production data available, collected in 2014, confirm that the plant is working perfectly and last year produced 306,000

KWh, or 6 MWh more than expected. The energy produced gives power to the Vatican electricity grid, generating a reduction in the absorption of electricity from the Italian grid by the Vatican.

3.4 Uffici Ghella: An Office Building in the Center of Rome

The retrofitting of the building that houses the headquarters of the construction company Ghella s.p.a., built in 1973, aims to preserve the strong architectural character of the existing building, improving the quality of the workspace, and reducing the use of energy, and CO_2 emissions [7, 8]. The building consists of two parts connected to each other, located at the ends of the triangular lot. The distances between the two buildings define a central space covered by a reinforced concrete grating and crossed by two connecting bridges. There are five floors above ground and a basement for a total area of 5000 m^2. The building has never housed the shops for which it was designed, since its first use it has housed public offices. In 2007, the year in which Ghella bought it to make it its headquarters, it was in bad internal conditions, but the structures did not show serious conservation problems demonstrating the care given to the packaging and execution of the works in reinforced concrete (Fig. 5).

The energy problem has been placed at the center of the design action, although the redevelopment project had to respond to multiple aspects concerning the spatial organization, the interior finishes, and the overall image of the building. Energy redevelopment is accompanied by a general redevelopment of the building where the containment of consumption, or more generally an adaptation to more environmental requirements, becomes a part of the entire intervention. Solar thermal (ST) collectors are selected for domestic hot water (DHW), and radiant heating. To this purpose, flat ST collectors are positioned on the 5th floor central terrace, to be visible by the offices. Vacuum ST are selected for their high efficiency. They consist of glass tubes of about 2 m with a diameter of 0.10 m, which inside in a condition of absence of air contain copper sheets that collect solar radiation. The ST collectors become a technological pergola that covers part of the terrace. The individual pipes are rotated to the south. In this way, the copper sheets form an angle of 30°, and the rotation allows horizontal positions for the panels, without decreasing their efficiency. Also, they have a different permeability to light according to their

Fig. 5 Façade and PV canopies on the building roof. (Source: Elena Lucchi)

orientation. To avoid overheating of the fluid, a curtain is inserted above the panels and controlled by a temperature sensor. This electrically controlled 4 m × 10 m tent is used for shadowing the terrace. In parallel, semitransparent PV panels are integrated on the roof for a total of 30 Kwp used for heat pump generators associated with the radiant floors, artificial lighting, and systems supervision of the building. The result in terms of energy classification was to bring a building with serious initial energy problems to class A.

3.5 Palazzo Leonori: An Insurance Office Building in the Center of Rome

Palazzo Leonori is located in via delle Mura Portuensi, in the southeastern part of Trastevere. Immediately outside the circuit of the seventeenth-century walls, the Palace was built during the 1920s, in an area that for most of the modern age had been occupied by vineyards and vegetable gardens, which experienced a progressive urbanization only from the end of the nineteenth century. The renovation project aims at re-establishing a unitary block, integrating new single-story volumes, replacing the existing ones, and open spaces with the function of equipped atrium. The main renovation interventions, carried out between 2012 and 2017, concerned the demolition of the external volumes in the courtyard on the ground floor (single-story buildings) and the superfetation on the fourth floor (additional buildings) and their reconstruction, with more appropriate and efficient construction characteristics, partly at the ground floor, inside the courtyard, partly on the fourth floor to integrate the existing volumes [9, 10]. The new one-storey buildings in the courtyard were covered with a large metal roof structure with semi-transparent BIPV and windows with motorised openers, coinceived as a bioclimatic atrium (Fig. 6). Other interventions involved the construction of an underground garage floor, the adaptation and redevelopment of the main building with the insertion of two lifts; the demolition and reconstruction of the internal staircase to serve also the basement and roof floors, the rehabilitation of the basement, new bathroom groups, redistribution of interior spaces.

The bioclimatic atrium built south of the building has the dual function of a passive heat accumulator and an active producer of clean energy. It is detached from the

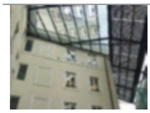
Fig. 6 Glazed PV roof with iron structure of the atrium. (Source: Elena Lucchi)

wall to ensure minimal intervention and natural ventilation. The glazed envelope, which encloses the full-height space between the building and the Atac depot, is in fact characterized by a large surface inclined at thirty degrees with the insertion of semitransparent integrated PV modules (light thru). The 60 semitransparent photovoltaic modules, each measuring 2 square meters, have a peak power of 181 Wp. The total power of the solar system is therefore equal to 10.86 kWp.

4 Assessment of the Case Studies

The case studies are discussed in a focus group with 17 conservators of the Italian HA in the framework of the Research Project Interreg Italy-Switzerland "*BIPV meets history*" [11] to understand pros and cons of the different approaches. People involved have an architectural background, with a degree, a specialization course and, in many cases, a PhD on architectural heritage and landscape (Table 1).

Table 1 Results of the discussion with HA on the risk-benefit assessment of the case studies

Building	Pros	Cons
	PV compatibility with original building and didactic purposes PV transparency and respect of original building geometry Multifunctionality (lighting, shading, energy)	Reduced energy production Irreversible system
	Respect of building appearance and values Low visibility of the system Transparency and multifunctionality (daylighting, energy)	Reduced energy production
	Symbolic value of the PV system Low visibility of PV from public areas Frameless system High energy production	Loss of historic materials Monochromatic color of pitch Changes of the original project of the roof Irreversible system
	Reduced visibility Transparency and color design that create a new building image Multifunctionality (shading, energy) Reversibility	Reduced energy production
	Protection of the historic integrity Transparency and modularity Building detachment, reversibility Multifunctionality (shading, daylighting, energy)	Reduced energy production

Source: Authors' elaboration

Several positive aspects are noted in the case studies:

- Safeguard of original features, materials, geometries, proportions, and values through historical research, minimization of losses, damage replacement, structural compatibility (examples 2, 4, 5)
- Reduction of PV visibility through concealment, color match, transparency (examples 1, 2, 4, 5)
- Tailored and detailed BIPV design, focusing on innovation and multifunctionality (examples 1, 2, 4, 5)
- PV reversibility of panels, and fixings (examples 2, 4, 5)
- Evaluation of alternative solutions, considering also original functions, and vocations (example 1)
- Balance between heritage conservation and energy production according to heritage constraints (all examples)

The risk-benefits scheme developed into the International Energy Agency (IAE) Task 59 is adopted, considering aesthetic, technical, energy, and environmental integration of PV systems [12, 13]. Solar integration criteria are divided in [12]: (i) "aesthetic integration" that implies a compatible material, visual, and spatial interaction with architectural features and PV components, which means heritage-compatibility with original materials, shapes, features, proportions, colors, reflectance, and patterns; (ii) "technological integration" that involves the multi-functionality of the solar component, which integrates the energy production with building functions (such as thermal and acoustic insulation, daylighting, shading, structural resistance); and "energy integration" that refers to the renewable energy production to cover the overall energy consumptions. The results of this discussion are reported below (Table 2).

5 Conclusions

The research assesses the integration of solar technologies in the refurbishment of five historic buildings in Rome, selected for their differences in function, construction periods, and architectural approaches. This analysis shows that an integration between solar technologies and historic buildings is still possible, respecting heritage values and features. Heritage-compatible transformation with active solar systems requires the ability to avoid irreversible changes, and tangible effects, designing *ad hoc* solutions based on a rigorous historical analysis of heritage values, materials, and features, as well as on a deep knowledge of PV and ST products, and solutions. The assessment requires a multidisciplinary team composed by conservators, architects, engineers, PV producers, energy consultants, and managers.

Table 2 Risk-benefit scheme applied to the case studies

Assessment criteria					
Aesthetic integration					
Material compatibility	■ red	■ green	■ red	■ green	■ green
Visual compatibility	■ green	■ green	■ green	■ green	■ green
Spatial compatibility	■ green	■ green	■ yellow	■ yellow	■ green
Technical integration					
Hygrothermal compatibility	■ yellow	■ yellow	■ yellow	■ green	■ yellow
Structural compatibility	■ green	■ green	■ green	■ green	■ green
Reversibility	■ red	■ yellow	■ red	■ green	■ green
Electrical compatibility	■ yellow	■ yellow	■ green	■ green	■ green
Environmental compatibility	■ yellow	■ yellow	■ yellow	■ green	■ green
Design, installation	■ green	■ green	■ green	■ green	■ green
Energy integration					
Energy performances	■ green	■ yellow	■ green	■ yellow	■ yellow
LCE	■ grey	■ grey	■ grey	■ grey	■ grey

Source: Authors' elaboration

■ (green) = No risks; ■ (yellow) = Low risk; ■ (red) = High risk; ■ (grey) = Absence of information

References

1. Lucchi, E. (2022). Integration between photovoltaic systems and cultural heritage: a socio-technical comparison of international policies, design criteria, applications, and innovation developments, *Energy Policy*, 171, 113303.
2. Official website of the Museum (2022). *Il Museo dei Bambini di Roma, Explora: la struttura*. Available at: https://www.mdbr.it/visita-il-museo/il-museo/. Accessed on 15/07/2022.
3. AeV Architetti. *Explora - Museo dei bambini di Roma - integrazione architettonica di sistemi fotovoltaici e bioclimatica*, http://www.aevarchitetti.it/scheda-museo-dei-bambini-roma.html. Accessed on 15/07/2022.
4. Cupelloni, L. (2011). Industrial archaeology and suburbs: Two cases of technological and environmental design. *In TECHNE - Journal of Technology for Architecture and Environment, 1*(2), 106–117.
5. Cupelloni-Architettura (2018). 2005-2007 / Città dell'Altra Economia all'Ex Mattatoio - Roma. Available at: http://www.lc-architettura.com/index.php/2005-2007-citta-dellaltra-economia-allex-mattotoio-di-testaccio-in-roma/. Accessed on 15/07/2022.
6. Online Journal (2015). Livio De Santoli fa il punto sul suo restauro fotovoltaico a due anni dalla realizzazione dell'impianto. Available at: http://cetri-tires.org/press/2015/livio-de-santoli-fa-il-puntosul-suo-restauro-fotovoltaico-a-due-anni-dalla-realizzazione-dellimpianto/. Accessed on 15/07/2022.
7. Raimondi, A. (2017). *Uffici Ghella – Building Retrofit*, Campisano Editore, Roma. Available at: https://www.ghella.com/sites/default/files/2022-04/Ghella_DEF.pdf. Accessed on 27/04/ 2022.
8. De Cristofaro, A., Di Mento, M., & Rossi, D. (2017). Coraria Septimiana e Campus Iudeorum: novità dai recenti scavi fuori Porta Portese. *Thiasos – Rivista di Archeologia e Architettura Antica, 6*, 3–39.
9. Altamura, C. I. (2017). Ristrutturazione edilizia di "Palazzo Leonori" da destinare a nuova sede delle Assicurazioni di Roma Mutua Assicuratrice.
10. Cler Soc. Coop. (2021). Manutenzione straordinaria ed ampliamento di un fabbricato storico; categoria OG2 – fabbricato vincolato: progettazione definitiva architettonica, strutturale ed impiantistica, https://www.clercoop.com/2021/11/06/ristrutturazione-palazzo-leonori-adir. Accessed 15/07/2022.
11. Lucchi, E., Baiani, S., Altamura, P. (2023). Design criteria for the integration of active solar technologies in the historic built environment: Taxonomy of international recommendations, *Energy and Buildings*, 278, 112651.
12. Polo López, C. S., et al. (2021). Risk-benefit assessment scheme for renewable solar solutions in traditional and historic buildings. *Sustainability, 13*, 5246.
13. Lucchi, E., Schito, E. (2023). Challenges and Opportunities for the Integration of Photovoltaic Modules in Heritage Buildings Through Dynamic Building Energy Simulations. In: Furferi, R., Governi, L., Volpe, Y., Gherardini, F., Seymour, K. (eds) The Future of Heritage Science and Technologies. Florence Heri-Tech 2022. Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-031-17594-7_14

Integration of Solar Technologies in Historical Buildings: Construction of an Evolutionary Framework of Good Practices

Serena Baiani, Paola Altamura, Elena Lucchi, and Giada Romano

1 Introduction

"Any project concerning historic buildings cannot disregard the following considerations: […] the preliminary and fundamental attention to the monument/document (of historic/artistic interest) to be protected as architectural 'image' and as 'material culture', that is an object derived from craftsman like techniques and skills which are historicized and have become authentic 'vestiges' of civilization [and] the adoption of the concept of 'energy efficiency' not as a burdensome added restriction, but rather as a useful instrument of protection and sound management of architectural objects, and more in general, of the buildings that are part of the cultural heritage" [1]. Focusing on the Italian context, the paper analyzes, based on the intrinsic relationship between architecture and the sun, the criteria for integrating photovoltaic solar technologies in historic buildings as a means of adapting the architectural heritage to the requirements of energy production from renewable sources.

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2 Historic Building and Solar Radiation

"Historic city has always been a solar city." The statement by Sartogo [2], a pioneer in the study of the historical matrices of solar architecture, clearly identifies the relationship between the historical fabric and microclimatic phenomena that determined the design of the historic city in close relationship with the natural ecosystem. The orography and climate, sun, wind, and water had a fundamental role in the choice of location for the historic city's original design and growth. Morphology results from a specific result of the relations between a system of rules ranging from the design of the matrix axes to the road framework, land division, building typology, and the system of aggregation into urban fabrics, together with the effects of the climatic, orographic, and geographic conditions of the site. According to Vitruvian rules, sun exposure and wind direction constitute the main coordinates for the orientation of the urban network of the settlement (a clear example is the castrum). The main axis, the "cardo maximus," in temperate climatic areas is oriented similarly to the centurial divisions of the agricultural fabric, in a north-south orientation and according to the direction of the north and south quadrant winds, with some variation in inclination due to the orography of the place, which did not exceed 20–30°. Historic architecture, in Mediterranean basin, assumes a type-morphological structure in coherence to microclimatic characters of site, defining the optimization of energetic relationships with surrounding natural environment. The building—as fluid, adapted, sensitive interface, superficial border line that is able to define the relationships with environment and to model itself on environmental factors—finds in technological environmental design tools and criteria to make a dialog with climate and natural elements: sun, wind, light, water, and vegetation are materials and sources of energy that the project makes to selectively interact with the context, in a continuous exchange of material and energy, determining an equilibrium of transformations. Built without systems, with the exception of fireplaces and wood-burning stoves, the building used bioclimatic behaviors for the livability of spaces in different seasons, in different contexts: natural ventilation for cooling; the canalization of air that from the basement spaces, at a constant temperature throughout the year, ensured preheating and precooling with exchanges of hot and fresh air for the rooms on the ground floor; the shading and light regulation systems (pergolas, porches, galleries); the intrusion of greenery and the collection/reuse of water to control temperature and humidity; natural lighting in relation to exposure and the size of the openings; optimization of the typology with the use of local materials and construction techniques. Architectural morphologies derive, therefore, from the relationship between microclimatic conditions and adaptive capacity in the use of climate factors: flat roofs for water drainage and sloping roofs to limit snow load, loggias as buffer and solar capture spaces, grids, and porous surfaces for heat exchange between different levels. Historical buildings, designed and built considering the bioclimatic characteristics of the site, traditionally ensured comfortable environments using the available renewable resources, as solar energy, dominant ventilation, and rainfall [3], designing, in a differentiated way according to the microclimatic conditions, envelopes as fluid, adaptive, responsive interfaces [4], boundary lines able to define the relationships with the environment and to shape themselves on the environmental factors. The transferability of the bioclimatic approach (systems and technologies) to heritage design makes it possible to reconstruct the physical operation processes of architectural structures, enhancing their characteristics (orientation, radiation, shading, shape and compactness, envelope peculiarities, and material characteristics) in local microclimatic conditions, within the landscape context, to understand and increase their environmental efficiency. The shape of the building represents the key factor controlling energy performance, through the envelope, in relation to the shape ratio, surface-to-volume ratio (S/V), which allows the compactness of the system to be measured. The city and its monumental and historic buildings, consolidated through the long centuries of their history, were conceived in relation to the sun. The study and research of the interpretation of energy and bioclimatic values in the structures of the ancient city, due to the environmental conditions, may represent, today more than ever, the key to a correct discipline for urban and monumental restoration [5].

3 Historic Building | Solar Energy: Integration of Renewables

Intervention on historical envelope imposes considerations of conservative matter, which, added to the need to introduce efficiency and effectiveness aspects, entails the inclusion of an additional phase of assessment in the design process. The objective of compatibility between protection, enhancement, and reuse requirements configures the intervention on cultural heritage as an insertion of the "*new adding elements*" (low energy consumption systems and equipment for conservation and use) within constraints imposed by the building envelope. A double analysis, from technological innovation point of view and limited transformability, imposed by the conservation of values, can lead to an intervention highlighting cultural identity in coherence with criteria of environmental sustainability and affordability. In the case of protected heritage or of historical and cultural value, design options are compared with the aims of conservation and transmission to the future, in the best possible material conditions. In this context, functional and energetic adaptation must follow the same purposes, which implies considering energy efficiency as a tool for conservation, rather than a redevelopment process in opposition to conservation requirements. It follows that design solutions must be made within an effective framework of comparison with the common operative criteria, included in the Restoration Charters: compatibility, minimum intervention, reversibility, distinguishability, expressive authenticity, durability, and respect for the original material. As for structural reinforcement, there is a need for a conceptual rethinking reflected in a new methodological approach within historical-critical process and scientific-technical procedure, oriented toward rigorous unity of method for the energy improvement in the architectural heritage, with the introduction of energy production systems from renewable sources [6]. While national legislation calls for a gradual increase in the use of energy produced from renewable sources, there are still several challenges related to the physical and morphological integration on historic buildings in the assessment of proper landscape and architectural integration (Building Integrated Photovoltaic or BIPV). The improvement of energy efficiency is the result of an operational assessed and customized for each building. It involves a set of interventions for guaranteeing compatible and tailored interventions (refurbishing, total or partial renovation, restoration, maintenance), also ensuring human comfort, and optimized operating costs. In coherence with many recommendations derived from Restoration Charts [7], the common principles suggested by the literature are evident: in a *minimum intervention approach*, it is necessary to work toward *distinguishable*, as the addition must be easily identifiable from the original support, without disturbing the overall perception of the work; *reversibility* of the intervention, which allows the addition to be removed without any deterioration or damage to the original components; but above all to work with the chemical-physical and aesthetic compatibility of the materials, which does not lead to any constructive or aesthetic alteration. In the integration of energy efficiency systems, it is important to preserve historical value of the components and the adoption of technologically innovative solutions that are compatible, also from a morphological point of view, containing the level of intrusion and perceptibility [8, 9]. The basis is the multidisciplinary approach, which emphasizes the importance of collaboration to involve and interface with different specialized experts. National Regulations allow the identification of intervention criteria oriented to the perception of the PV system. Emerge as Fundamental criteria for the design, emerging from this regulatory framework, are: the conservation of external aspects, using formal solutions, materials and compatible and coherent colors and the installation of new systems, the adaptation and/or refurbishment of existing ones planned according to solutions of adequate design quality, with the adoption of technological solutions compatible with the historic and landscape values [8]. Fundamental design criteria are the preservation of "aesthetic aspects" using compatible and coherent morphological, material, and chromatic solutions; the integration of new systems, the adaptation and/or renovation of existing according to solutions of adequate design quality, with the adoption of technological solutions that are compatible with historical and landscape values. In this framework, the definition of "compatibility" as the "extent to which one material can be used with another material without putting heritage significance or stability at risk" is referred to international standard [10]. The meaning is transferred to the technical elements for energy production, integrated in the building components, in terms of technical/constructive compatibility; aesthetic compatibility; and energy/functional compatibility. International Guidelines (as manuals, guides, online platforms) for the integration of solar technologies in cultural heritage define different approaches, main criteria, and recurrent recommendations, with a different interpretation according to the local conservation culture. Recurring is a double vision of the intervention that identifies two differentiated solutions: the technical component of the roof, with the option of the physical

Fig. 1 Examples of international guidelines. (Source: Refs. [11, 12])

integration of the energy system, and the addition (in adherence to or on other "minor" components of the historic building) that can support the energy systems. Guidelines emphasize the ways of integrating historical morphology and contemporary systems, identifying criteria for *aesthetic integration*, which indicates the correct perception of the building, in the absence of visual detractors; *technological integration*, which indicates the multifunctionality of the added technical components; *energy integration*, which measures the efficiency of renewable systems, within the overall energy setup [8] (Fig. 1).

4 Design Project, Evaluation, Criteria

The interaction between historic buildings and the new energy production systems, in the design phase, with the aim of balancing energy saving requirements and protection, will have to be managed based on a high quality, educated, sensible design. Best practices show that renewable energy sources, with priority given to solar energy, crucial for mankind, are being developed through a process of research, dissemination, placing on the market and utilization. It is a fact that “energy efficiency in historic buildings proves to be a precious tool to promote protection, not least because paying attention to energy efficiency means a more accurate and measured design of technology solutions, and on top of this, ‘energy efficiency’ is an essential component of a sound and not expensive economic management of historic buildings, leading to a better use of these buildings. It is well known that ‘using’ a monument represents the most effective tool of protection, due to the fact that it is not left in a state of neglect and maintenance has to be provided on a constant basis, with good prospects for handing it down to future generations” [1]. The Project, in the complex articulation of the different options, is supported by evaluation tools that guide the design elaboration phase through the input given by the criteria derived from the regulations and the scientific literature and allow, in the evaluation and verification phase, the control and measure of the level of compatibility of the intervention on the existing heritage. The integration of energy systems is considered compatible with historic architecture if it is “acceptable,” if it is in correct balance between the level of conservation of the heritage value and the visibility of the roofing (technical component of the envelope prepared for integration) from the surroundings. Therefore, energy systems are considered compatible with the existing building if they are installed in an integrated manner, adhering to, replacing, or overlapping the roof covering, with a coherent inclination and orientation of the pitches, using a color reference consistent with the original. Tools to support the designer and evaluator have been developed in various research fields, often referring to architectural integration in a new building. Interesting are two tools, promoted within European experiments and research, that focus on the appropriate design of contemporary technical systems integrated on the existing building. The first aspect, which determines the feasibility of integration, is related to the “visibility” of the energy system: the level of “criticity” of a surface is defined by the sensitivity of the urban context and by the visibility of this surface from the public domain (LESO-QSV), per cui the more sensitive the urban area, the more visible the surface, the higher its “criticity,” and consequently, the need for quality in integration [13]. The assessment of the visibility of the energy system, in relation to its location on the roof, is referred to in the LESO-QSV tool, which identifies two main conditions (Fig. 2).

A simplified graphical tool for verifying the visibility of the solar installation on the roof is developed [14]. Regarding the need for simplified tools for the visual

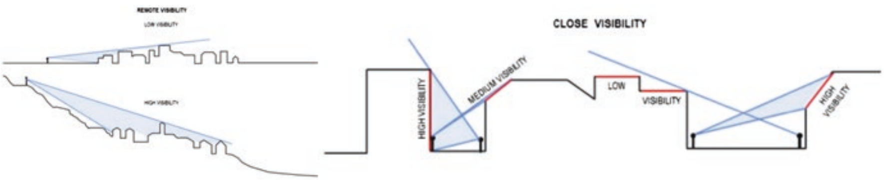
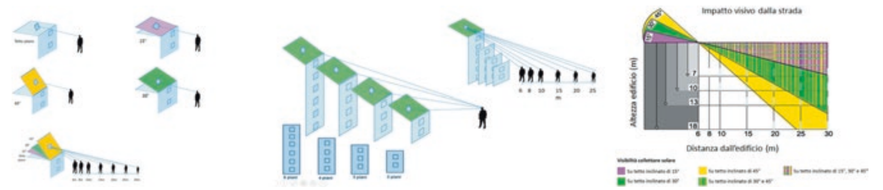


Fig. 2 System visibility. (Source: LESO, EPFL)



Evaluation for different roof pitches (flat roof, 15°, 30°, 45°) at different distances from the building (6-30 m) of the observer

Evaluation for different heights in the building (2, 3, 4, 6 floors) and from different distances (6-30 m) of the observer from the building

Scheme for checking visibility from the street of differently inclined roofs, also varying the distance of the building and its height

Fig. 3 Evaluation of the visual impact of various solar systems (Source: Ref. [14])

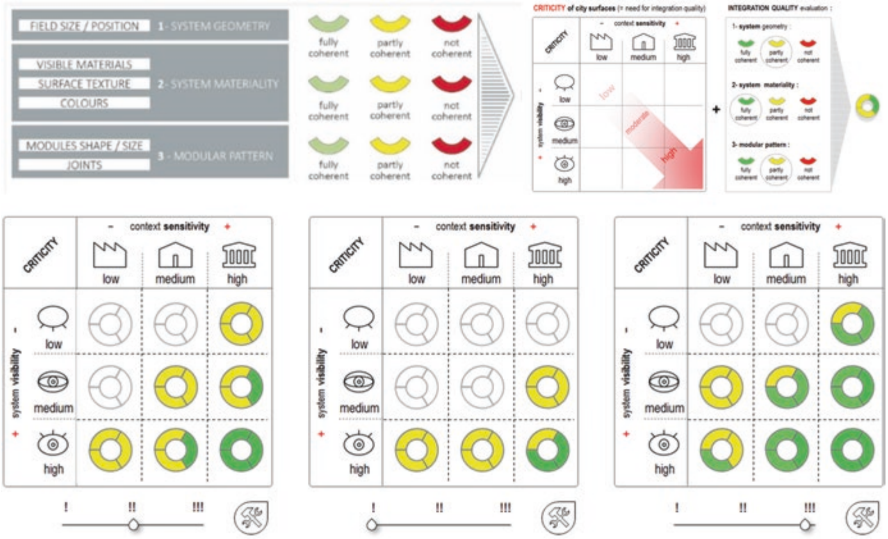


Fig. 4 Criticality matrix developed in relation to context. (Source: LESO-QSV – Architectural integration tool, https://www.epfl.ch/labs/leso/research/domains/renewables_integration/leso-qsv)

impact assessment, a graphic tool evaluates the proposal of integration in the roof, varying the distance of the observer, the roof pitch, and height of the building (for the designer to verify the degree of visibility from the street; for evaluator to verify that the project meets certain requirements related to the visual impact). The result is a graph that combines three variables (distance from the building, building height, and slope of the roof) to verify the impact that a technology placed in the roof, from a frontal position (Fig. 3).

Next phase defines minimal local levels of integration quality and identifies the factors to set smart solar energy policies, able to preserve the quality of existing urban contexts while promoting solar energy use. In this case, "LESO-QSV. Architectural integration tool" method supports choices, and optimizes evaluations during the project phase [13] (Fig. 4). The tool clarifies the notion of architectural integration quality and proposes a simple quality evaluation method, based on a set of three criteria derived from scientific literature. Then it helps authorities set and implement local acceptability requirements, based on the notion of architectural “criticity” of city surfaces (LESO-QSV acceptability).

The “criticity” is defined by the sensitivity of the urban context where the solar system is planned and by its visibility (close and remote). To help authorities setting these quality expectations, a specific software has been developed to show the impact in acceptancy of predefined sets of quality requirements over a large number of integration examples. These documented installations are also provided as a model for authorities on how to objectively evaluate integration quality and constitute a large set of inspiration examples for architects/installers/building owners.

Finally, the method proposes a way to adapt solar energy policies to local urban specificities by mapping the architectural “criticity” of city surfaces, and crossing this information with the city solar irradiation map (LESO-QSV cross-mapping).

The obtained cross-mapping weights the irradiation on a given surface with its architectural criticity, evaluating the interest/difficulty to use this surface for solar energy production, helping setting priorities of intervention, planning oriented subsidies [15]. The procedure SuRHiB Sustainable Renovation of Historical Buildings defines criteria and recommendations for different building typologies, and surfaces for solar installation (Fig. 5). The visual appearance of the modules and the grid formed by the modules together can influence evaluation of the project. Thus, the research proposes a set of criteria for examining projects to install solar technology on the roofs of historic buildings, complete with technical and aesthetic recommendations that extend beyond just the aspects of geometry and positioning of solar panels on roofs, focusing on visual impact. One of the first requirements to improve the architectural building quality with solar installations is to define and then try to reduce the morphologic limits to identify the most appropriate solutions.

The objective requirements do not exclude the analysis of each specific case and are particularly crucial in historic buildings or areas where the proposed

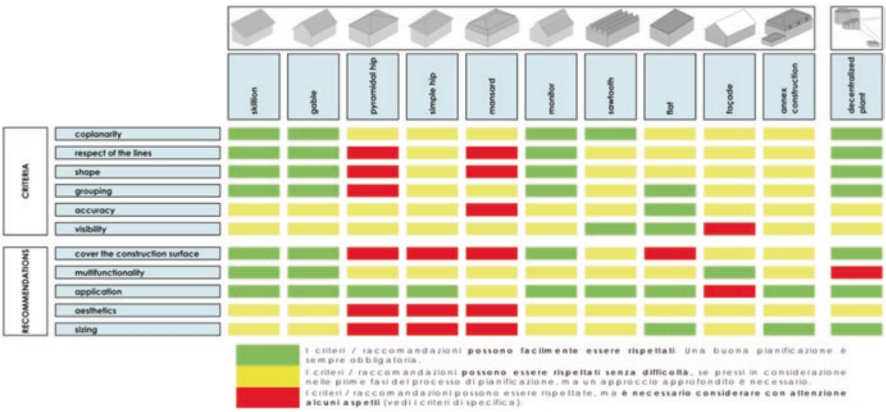


Fig. 5 Summary table of feasibility criteria for solar collector installations. (Source: Ref. [15])

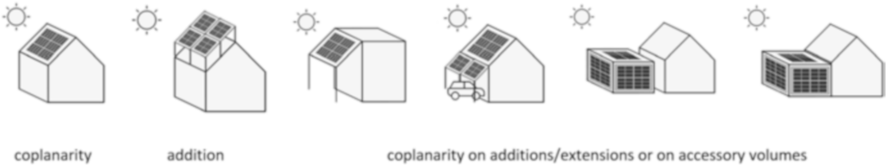


Fig. 6 Main criteria of integration. (Source: Authors' elaboration)

intervention must be evaluated from different points of view. The requirements taken into consideration are coplanarity, respect for line, form, grouping of elements, accuracy, and visibility [16].

Several studies show that the evaluating authorities are adopting fundamental criteria in the integration: the aesthetic characteristics of the panels (color and surface finish); the geometric arrangement in relation to the shape of the pitches and the orientation of the building (shape of the system, modularity); adherence and coplanarity to the roof; nonreflective surfaces; perceptibility from the surroundings, with reference to the height of the street and the landscape. In addition, studies of cases of photovoltaic systems applied to buildings, giving information around technologies [17, 18], defines specific criteria for correct fixing systems as *coplanarity* of photovoltaic modules in connection to roof surface (without substitution of components or materials in case of partial or total integration); *respect of the eaves* line by module that not exceed the upper edge of the tiles by more than its thickness; *respect the geometry* of the pitch in the location of modules; *compactness of the modules* to reduce space between external perimeter of the modules and the residual portion of the existing roof. The design solutions have been compared with recommendations (GLs and regulations) for historic buildings with reference to limits to the transformation, identified in the scientific literature [9, 18, 19] and resulted that perceptive-cultural constraints aimed at preserving symbolic, historic, stylistic, and artistic features, respect for the collective memory, and aesthetic interactions with the landscape; morphological-dimensional constraints aimed at preserving the geometric configuration and stereometric characteristics of the envelope; material-constructional constraints aimed at preserving the building materials and techniques, as well as their performance [20] (Fig. 6).

5 Conclusion

The analysis of the Regulations and Charts made it possible to identify criteria for intervention on existing buildings centered on physical, morphological, and perceptual compatibility. A fundamental character of any action is the reversibility of contemporary intervention on historical structures, for the conservation of material and cultural values. With this objective, the disassembly for updating and replacement of components assumes fundamental importance in the transfer of the criteria of reversibility building to each technical action applied to the historic building. The evaluation of the technical criteria and compatibility criteria on the existing building took place through the reading of international case studies, selected according to different parameters, to understand possible modalities of intervention on existing buildings, identifying levels of integration, morphologies of the integrations, disentangling materials of the integrated technological devices and evaluating energy efficiency of technical systems. The final synthesis framework, currently being elaborated, will delve into the technical systems used in the different cases, opening up to the identification of innovative products with a high level of customization, which reduce the visual impact and improve the aesthetic and chromatic acceptability of photovoltaics. Based on the case study analyses, an attempt will be made to assess efficiency levels of the photovoltaic system according to the different techniques used and efficiency levels unit for a comparison between the case studies in the different phases, to understand the actual sustainability of the intervention. Finally, the research will compare criteria from LGs, standards and case studies to develop shared synthetic criteria, based on an international glossary, to support the project, which can be verified and evaluated.

References

1. Carbonara, G. (2015). Energy efficiency as a protection tool. *Energy and Buildings, 2015*, 95.
2. Sartogo, F., Bastiani, M., & Calderaro, V. (1995). *The Mediterranean city organism. Ecological, bioclimatical, methodological and structural urban continuity*. Rebuild European Conference: Book proceedings, Corfù.
3. Butera, F. (2006). *Dalla caverna alla casa ecologica*. Edizioni Ambiente.
4. Herzog, T., Knipper, R., & Lang, W. (2004). *Facade construction manual*. Birkhauser Architecture.
5. Sartogo, F., & Bastiani, M. (1998). *Manuale metodologico per il recupero delle strutture bioclimatiche del centro storico di Perugia* (Rebuild). Edizioni Guerra.
6. de Santoli, L., Bellia, L., Corgnati, S. P., et al. (2014). *Efficienza energetica negli edifici storici*. AICARR.
7. ICOMOS. (2004). *International Charters for Conservation and Restoration = Chartes Internationales sur la Conservation et la Restauration = Cartas Internacionales sobre la Conservación y la Restauración* (Vol. I). Documentation; Monuments & Sites. Available online: https://openarchive.icomos.org/id/eprint/431. Accessed on 10 July 2022.
8. Lucchi, E. (2023). Renewable Energies and Architectural Heritage: Advanced Solutions and Future Perspectives. *Buildings,* 13, 631.
9. Lucchi, E., Baiani, S., Altamura, P. (2023). Design criteria for the integration of active solar technologies in the historic built environment: Taxonomy of international recommendations. *Energy and Buildings*, 278, 112651.
10. European Standard. *Conservation of cultural property – Main general terms and definitions*. EN 15898:2011. 3.3.3. Conservation terms. Compatibility.
11. Direction Environnement et Cadre de vie Service Energie. (2019). *Pour l'integration architecturale des capteurs solaires*. Aix-en-Provence.
12. CAUE. (2015). *Le Guide des capteurs solaires*. Région Languedoc-Roussillon.
13. Munari Probst, M. C., & Roecker, C. (2015). *Solar energy promotion and urban context protection: LESO-QSV (quality – site – visibility) method*. PLEA 2015, Proceedings, Bologna.

14. Dessì, V. (2016). Visibility assessment of the integration of technologies from R.E.S. in sensitive urban environments. Proposal for a simplified fraphical tool. *EWT Eco Web Town, III/2015-I/2016*(13/14), 1–14.
15. Formolli, M., Croce, S., Vettorato, D., Paparella, R., Scognamiglio, A., Mainini, A. G., & Lobaccaro, G. (2022). Solar energy in urban planning: Lesson learned and recommendations from six Italian case studies. *Applied Sciences, 12*(6), 2950.
16. Zimmermann, M. (2013). *Sustainable Renovation of Historical Buildings (SuRHiB)*. Final Report.
17. GSE. *Guida agli interventi validi ai fini del riconoscimento dell'integrazione architettonica del fotovoltaico*. https://www.vegaengineering.com/mlist/uploaded/GSE%20-%20guida%20integrazione%20architettonica%20del%20fotovoltaico.pdf. Accessed on 10 July 2022.
18. Lucchi, E. (2022). Integration between photovoltaic systems and cultural heritage: a socio-technical comparison of international policies, design criteria, applications, and innovation developments. In *Energy Policy,* 171, 113303. Elsevier.
19. Polo López, C. S., Lucchi, E., Leonardi, E., Durante, A., Schmidt, A., & Curtis, R. (2021). Risk-benefit assessment scheme for renewable solar solutions in traditional and historic buildings. *Sustainability, 13*, 5246.
20. De Medici, S. (2021). Italian architectural heritage and photovoltaic systems. Matching style with sustainability. *Sustainability, 13*, 2108.

Blow-Up Sustainable Modular Houses for Slum Dwellers Amid Covid-19

May Elhadidi, Haidy Mousa, and Pietro Tonini

1 Introduction

Cities are the most significant concern of major economic, social, demographic, and environmental transformations. During the last 20 years, the growth of the urban population in the cities, especially in developing countries, made challenging the generation of enough housing and employment along with other social infrastructures such as education and health services [1]. As a result of this growth, many people from developing countries are living in urban slums, particularly in sub-Saharan Africa, South-central Asia, and Eastern Asia. This unplanned quartier developed at the edge of the main towns are physical and spatial manifestation of urban poverty and intra-city inequality and represents about 60% of housing worldwide [2].

Among the issues that face the slums, unemployment, the absence of basic needs, unhealthy living conditions, and high crime rate are highlighted as the most important issues [3]. Most slum dwellers are in low-paying occupations such as informal jobs in the garment industry, recycling of solid waste, and a variety of home-based enterprises and many are domestic servants, security guards, piece rate workers, self-employed hairdressers, and furniture makers. Informal jobs mean that people within the slums do not have a stable income, thus preventing the possibility of

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investing in improving their conditions. The low-income level and the location on the edge of cities make that few houses are connected to stable supply of water and power. The absence of potable water, private toilet, and a system for disposing of garbage and sewage, generally left in open air, is at the root of the health risks present within the slums [4]. Moreover, the poor sanitation is also exacerbated by the fact that the house is located close to each in an uncoordinated manner reducing the level of ventilation on the quartiers [5]. Finally, the low standard of living, high food insecurity, and absence of controller fuels the levels of crime within these quartiers. In particular, the main target of abuse and violence are people at risk of exclusion, such as women and children, migrants, and persons with disabilities. These structural problems make the slums low resilient to external events threatening the already unstable quality of life within the slums with an impact on the area around it.

Climate change and Covid-19 have shown that the challenge related to the slums are not local and confined to low-income areas but can undermine broader development and even political stability [6, 7]. Indeed, the increase in extreme weather and catastrophic events such as heat wave frequency, flood, and drought as well as air pollution have seriously worsened the quality of life and raised the inequalities [8]. Moreover, the difficulty to do lifesaving practices like handwashing and the high density of population in the slums converted the dwellers into vectors during Covid-19 accentuating the marginalization of these areas from the cities [5].

As what happening in the cities of the developing countries, and in particular in the slums, through the coming years, will significantly shape the prospects of global economic growth, it is important to provide specific solutions for this area [3]. Based on this challenge, this paper represents an attempt to introduce through smart architectural solutions a sustainable, self-sufficient, and integrated urban settlement resilient to climate change challenges, and pandemics such as Covid-19. In particular, the project wants to propose a holistic approach for the slums to mitigate food poverty, increase the energy and clean water access as well as improve health, educational, and cultural services.

The case study of the slums of Sudan is identified because is one of the poorest countries of the world and with the largest proportion of the urban population resident in slums (71.9%) [9]. Despite the abundance of mineral resources and fertile agricultural land, 60% of the population live below the poverty line, over 35% of the children under age 5 are underweight, and only one-third of the population completed primary studies [9, 10]. The biggest problem blocking the country's development is the lack of reliable infrastructure especially during the rainy season where 60% of the road are not accessible [11]. Climate change-driven flooding and drought are threatening to aggravate an already precarious situation in vulnerable parts of Sudan. During 2021, the project site experienced the worst flooding on record while other areas in Sudan suffered from droughts. These climate change impacts made the accessibility to housing and food difficult and the number of refugees increased [12]. Access to some of the most vulnerable populations is a major impediment for humanitarian interventions due to the high level of tensions inflamed by the unresolved issues lingering from the secession of Sudan.

2 Methodology

The study methodology depends on inductive and analytical approaches: the first part includes a review on the site and culture and the second part includes the design of a prototype and its adaptability to the site and the community. The work also analyzed different adaptive techniques implemented in this project using innovative architectural solutions and technologies. This work was a part of winning project in the WREC 2020 International Student Competition: HOME KIT for sustainable modular houses for slum dwellers amidst Covid-19.

3 Concept

The project's approach is biomimicry, where the concept of housing is similar to the exoskeletal hermit crabs that carry an unstable life similar to that of slum dwellers. Their shell is the portable, protective, replaceable temporary habitat. The house consists of a main structure that expands and transforms according to the family and the needs of future pandemic situations. The walls of the house are made of an inflatable material that is covered in a removable skeleton to expand and create new rooms or enlarge the house. It allows the house to be flood-proof, making it possible to transport the system from one area to another and relocate it in the event of natural disaster. Figure 1 shows the structure analysis of the prototype home.

4 Architectural Interventions and Innovation

4.1 Climate Resilience and Portability

Innovative architectural solutions are proposed to make the units resilient to climate change crises such as floods and droughts as the massive flood that hit Khartoum, Sudan, back in 2020, which destroyed mud brick houses. The home-kit core structure is made of waterproof plastic wastes designed to form inflatable air cushions that lift the house on water and facilitate its portability over water to relocate it in a safe zone after the flood. During relocation, the homeowner can remove the outer shell and reassemble the house into a floating cube, and after the crisis ends, it can be reassembled again to its original state as illustrated in Fig. 2. In order to provide sustainability of the house structure and resilience against weather, the plastic inflatable cushions are replaceable and easily made by residents themselves from recycled plastic sheets. To insulate the house from hot weather and sand, the core is covered from the inside and outside by recycled cardboard sheets or woven straw sheets manufactured locally by the Sudanese people.

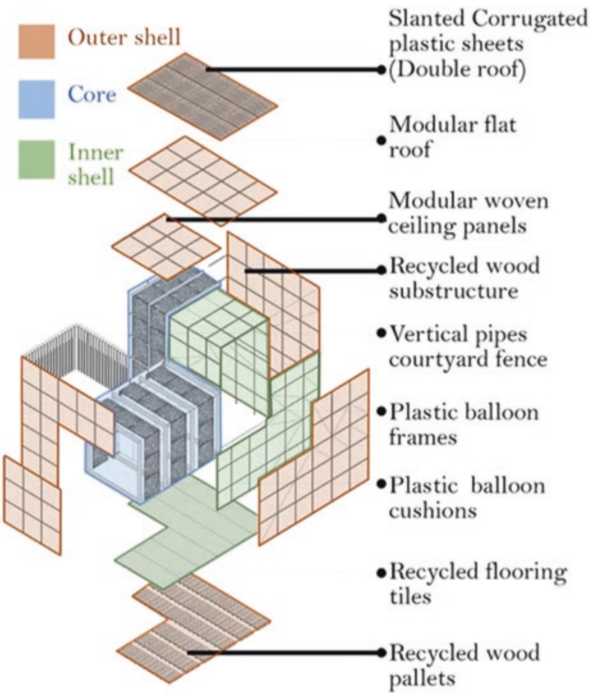

Fig. 1 The structure analysis of the prototype home

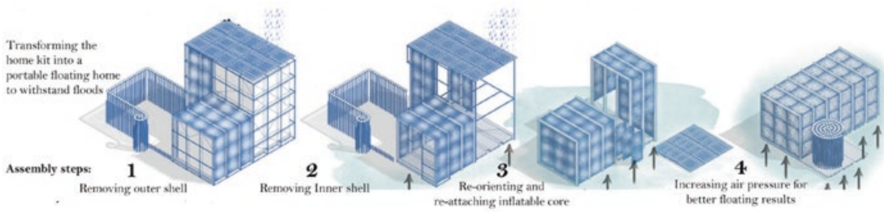

Fig. 2 Assembly steps during floods to facilitate portability. (Source: Researchers work)

4.2 Family Homes Expansion and Dynamic Modules

The dynamic structure explained above facilitates reassembly into different layouts that expands the house to include a larger area according to family needs. The project proposes six different layouts, three steps for enlarging the house to hold new family members and three different proposals for the house for five members (50 sqm area) to offer the family design options according to their needs as in Fig. 3.

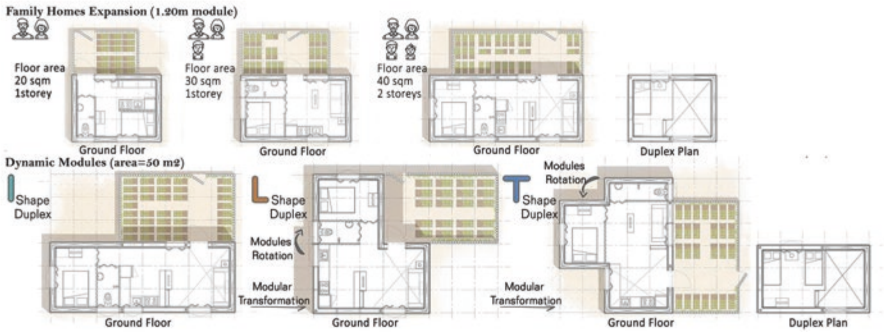

Fig. 3 Dynamic design options according to area and orientation. (Source: Authors work)

4.3 Dynamic Interior and Furniture

In order to use houses' small areas efficiently all day long 24/7, the furniture selected has to fulfill multiple purposes and have dynamic orientations so it can suit different functions during the day such as family gatherings, dining, working, and studying. Folding doors and windows suit the small area and can reshape the interior space according to its use as well as furniture made of recycled blocks that can be assembled in any shape to form multiple pieces, e.g., armchairs or sofa or sofa bed.

5 Cluster Design

The clusters were designed to serve each other to be resilient, adaptive, and self-sufficient. The homes can be rearranged in case of family expansion, adding more activities or pandemic emergency. Each cluster has a modular shared space that can be fitted into any space form. Besides, the structure of the shared space is affordable and applicable to the residents to build. The design and the features of the clusters aim at achieving the three pillars of sustainability in order to be livable, viable, and equitable as illustrated in Fig. 4.

5.1 Economical Security

Economical security was achieved by engaging circular economy into the community's lifestyle through exploiting the activities of each cluster in commercial activities to create local jobs. These commercial activities are represented in local markets and street vendors which sell the crops that the residents grow in their homes or sell

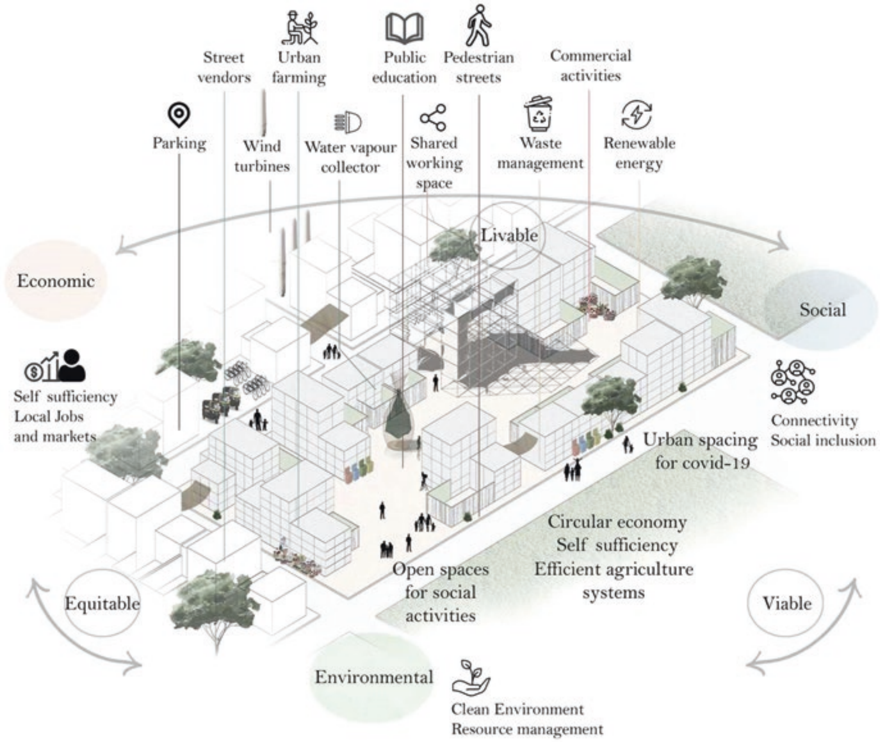

Fig. 4 The clusters features

their local products, and waste management through waste segregation and Bokashi composting to benefit from the outcomes in fertilizing the soil, recycled furniture, home accessories and products.

5.2 *Ecological Integrity*

Ecological aspect is the main factor that helps in clusters design, where the main aim is to manage the resources, provide clean energy, and maximize the usage of renewable energy. Therefore, each cluster includes spaces for wind turbines, water vapor collector, and rainwater harvesting, where these technologies have been selected based on the climate assessment in Sudan. Furthermore, the clusters were designed to be walkable for the residents to minimize the pollution.

The main source of income in Sudan is agriculture, so that it was important to create an efficient and sustainable agriculture system to cultivate the land using less amount of water and soil. This is achieved by using urban farming to create almost soilless vertical and horizontal farming, which depends mainly on natural light and water. Also, it was crucial to design a sustainable infrastructure for water supply and

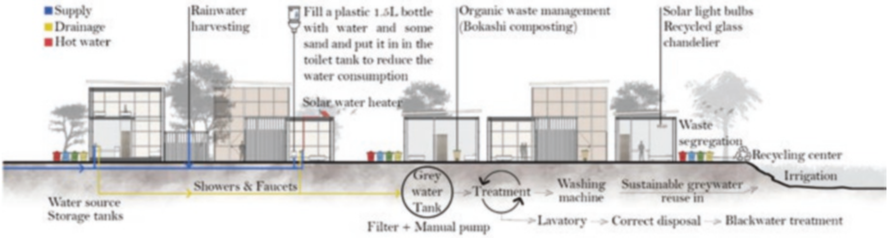

Fig. 5 Urban section of the infrastructure and recycling system

drainage as well as wastewater and greywater recycling which come from kitchens and toilets to be used in agriculture, toilet flushing, and street washing. The following section (Fig. 5) shows the efficient infrastructure and recycling system.

5.3 Social Well-Being

The slums development should focus on the human needs and patterns and consider their psychological needs to achieve social inclusion. Thus, the design includes open spaces for people to interact and socialize without affecting the productivity of work. Also, there are spaces for public education and awareness to develop their standards and understanding the importance of changing their life patterns to enhance their quality of life. The pedestrian streets were created for social and entertainment purposes and represent their culture aspects through art and music.

6 Sustainable Materials

To maintain the sustainable development of the housing area, sustainable building materials from natural local resources and recycled materials are selected as follows:

- Two options are proposed for the exterior and interior replaceable panels (Figs. 6, 7, and 8):
    1. Woven straw panels made by local inhabitants from natural straw waste in the site.
    2. Cardboard panels from recycled paper as they can also be used as drawing boards for educational and artistic purposes.
- The joining members that create the paneled structure and the garden's Green fence is made of reused PVC water pipes, which are available abundantly from old construction sites, and it can also be made of reinforced cardboard pipes made onsite.

Fig. 6 Woven straw panel. (Source: https://www.botanica-wood.be/fr/tressage-en-noisetier)

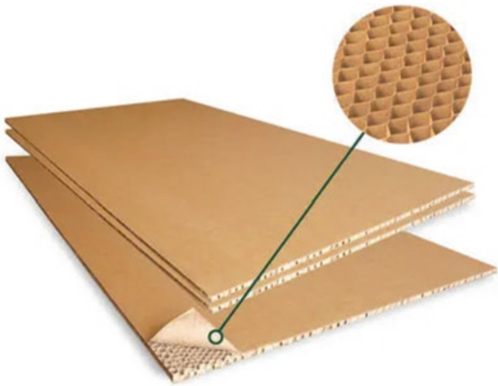

Fig. 7 Cardboard panels. (Source: https://www.directindustry.com/prod/360-eco-packaging/product-72554-2324281.html)

- The inner inflatable structure air pillows: These pillows have been made using plastic waste found on-site, which has resulted in a 50% reduction in material usage. The community can collect the plastic bags and compress them by heating to form air pillows, which act as the main core of the prototype's structure.
- Finally, flooring is made of plastic tiles: They are made of high-density polyethylene or HDPE. HDPE is commonly used for products such as shampoo bottles, water jugs, and bottle caps. It is waterproof, highly durable, and resists insects, rot, and other chemicals. Therefore, these tiles are available in the colors determined by plastic waste. They are available in a mix of different shades of each color and each tile is different from the other [13].

Fig. 8 The exterior finish of the house. (Source: Authors (Design renders))

7 Sustainable Technologies

In this project, many sustainable technologies and solutions were exploited:

- The inner inflatable structure air pillows: The sustainable air pillows previously mentioned can be utilized to form the inner structural frames and fill the wall cavities between them. When the wall structure integrates with a wooden pallet deck, it will create a lightweight, waterproof, floating structure illustrated in Fig. 9.
- Printing paper-thin solar panels: They require only an industrial printer to manufacture and they are inexpensive to produce. They are effective solutions for rural areas to maximize the use of renewable energy resources. Also, the panels can be printed on tissue paper, printer paper, newsprint, textiles, and plastic food wrap. They are characterized by their low-cost, flexibility, and durability that make them effective for slums where energy demand is growing and there is no power grid in sight as shown in Fig. 10 [14].
- Vortex bladeless: It is an induced vibration resonant wind generator and consists of a cylinder fixed vertically with an elastic rod which oscillates on a wind range to generate electricity as shown in Fig. 11. This divide is made of lightweight materials over a base, which reduce the usage of raw materials and the need for a deeper foundation [15].
- Solar water heater: It is an efficient way to generate hot water at low cost as it only depends on the sun. Solar water heating systems include storage tanks and solar collectors, and have two systems: active system, which have circulating pumps and controls, and passive system, which is less expensive and more reliable than the active one [16].

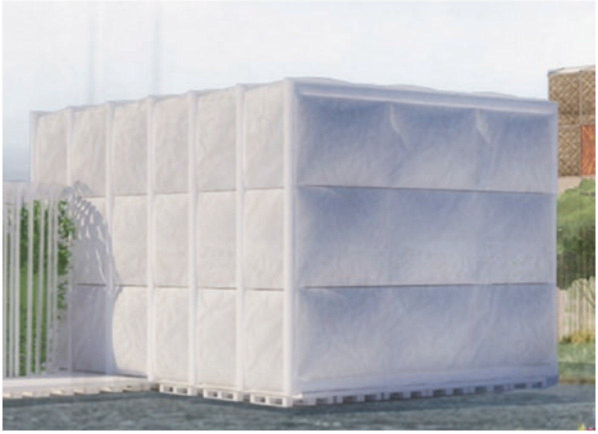

Fig. 9 Inflatable walls. (Source: Authors (Design renderings))

Fig. 10 Printing paper solar panel. (Source: https://inhabitat.com/printable-solar-cells-demonstrated/)

- Water vapor mesh collector: The fog collector consists of a fine-mesh net suspended within a steel frame. The net is held in space by rubber expanders, which are attached to the collector at its base, where the expanders generate strain on all four sides of the mesh to stabilize the seam at the net edges where the wind impact is concentrated. The water vapor in the air is trapped in the mesh, condensed, and drips down the mesh into a collector at the base (Fig. 12). This technology is useful because it is simple, cheap, easy to replace, and provide clean source of water [17].

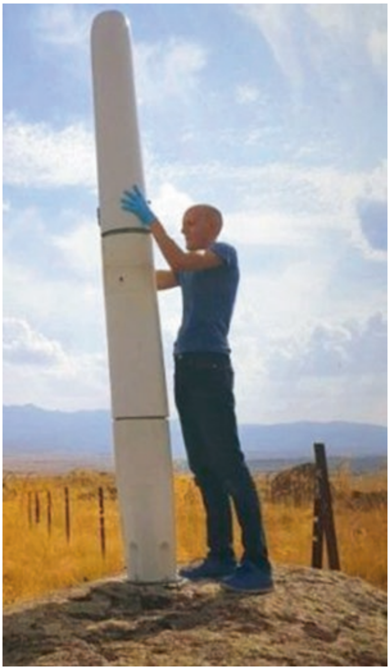

Fig. 11 Vortex turbines. (Source: https://vortexbladeless.com/cost-effectiveness-analysis-bladeless/)

8 Reaction to Covid-19

8.1 Effect of Covid-19 on Residential Scale

On the residential scale, considerations are taken in the design to cope with Covid-19 or any pandemic's measures. Thanks to the lightweight property of the structure and possibility of reassembling the unit, an isolation room can be created by rotating the main bedroom as in Fig. 13 and keeping the open space to be shared between the two masses. Flexible dynamic furniture as folding tables is also used to facilitate having a working zone in the living room.

8.2 Effect on Urban Scale

The clusters have various shapes with an outdoor area and shared working spaces. Every cluster is responsible for a specific activity to achieve a circular economy. During pandemics, every cluster has its work and social activities to be self-sufficient as illustrated in Fig. 14. The activities include waste management, wastewater management, plastic recycling, glass recycling, organic waste management (composting), and farming.

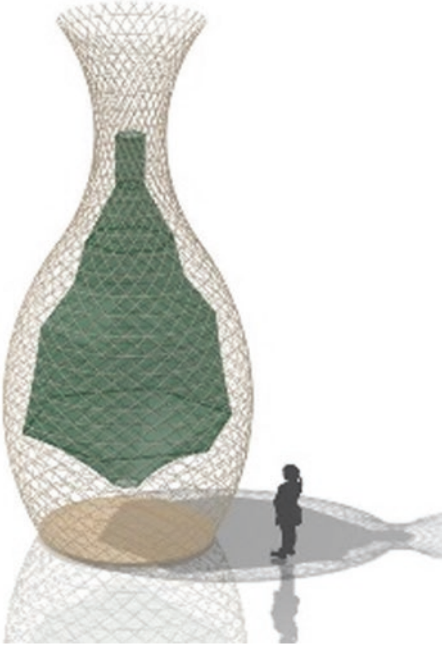

Fig. 12 Fog collector. (Source: https://livreinatural.uno/profiles/blogs/warka-recojer-agua-del-aire-por-condensacion?overrideMobileRedirect=1)

Fig. 13 House plan during isolation period

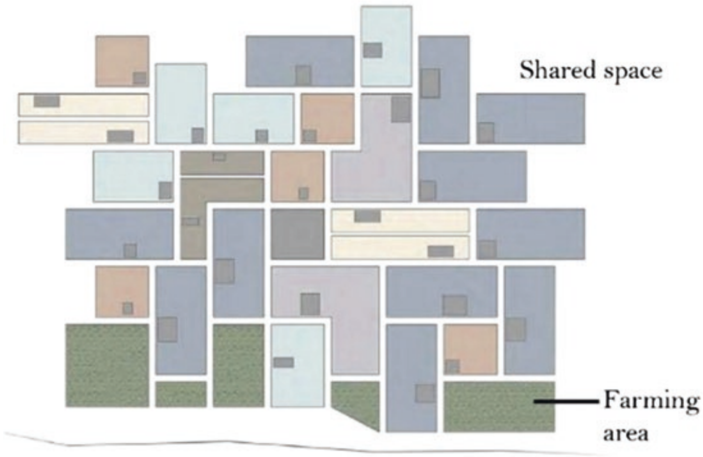

Fig. 14 The structure of the neighborhood

9 Cost Estimation

The estimation of the cost of materials was carried out in collaboration with an expert in design in cooperation and development in Africa, an agronomist with experience in urban agriculture projects [18], and a construction engineer (Table 1). The cost estimation was carried out following these steps: (1) identification of components (2) and their costs, (3) sum of component costs, and (4) approval of the budget by the agronomist and engineer. Once the cost estimation was finished, the final cost of the project in Sudan was estimated by the cooperation and development expert by translating the costs into the local currency and verifying the availability of materials.

10 Results

The assessments of the project revealed the following results. Table 2 shows the interventions in the project and their impact on the three pillars of sustainability (Fig. 15).

11 Conclusion

Through integrating sustainable technologies (Fig. 15), we can create new solutions to face crises like poverty, climate changes, pandemics and more to make the world a better place even with the limited resources available. Wastes can be turned into

Table 1 Estimation of the cost

Items	Description	Cost (€)
Modular house		7100.00
Balloon structure	Structure and cushion	2500.00
Furniture	Sofas, chairs, bed	650.00
Outdoor cladding	Woven straw panels	350.00
Vertical farming system	PVC pipes, tank, foot pump, biochair (substrate)	850.00
Solar panel	Printed solar panel (PET), battery, cable	1500.00
Rain harvest system	Umbrella, tank, tube, pump, sand	800.00
Flooring tiles	Recycled plastic bricks	450.00
Backyard		1900.00
Water management	Sterilight Copper SC2.5/2, sieve, gravel, storage tank, tube, valves	1200.00
Solar oven	Gosolar system	400.00
Simplified hydroponic system	Bio-chair, organic matter, plantlet	300.00
Total		9000.00

Fig. 15 Slum dwellers' life after enhancement that preserving the country's culture and identity

opportunities for unfortunate communities to give them hope for a brighter future. The project proposes an affordable sustainable architectural solution that can be implemented in areas threatened by climatic disasters as floods or instability of habitation. Providing social, economic, and environmental sustainability is made by creating a self-sufficient community that depends on one another to thrive as each individual has a role in his community development either in collecting and supplying building materials, assembly of houses, recycling of wastes, and planting crops. Further work can be done to experiment the proposed prototype in a real low-cost housing area and examine it in the post occupancy phase as the users can apply changes to the design to suit their ever-changing needs.

Table 2 Sustainable development pillars assessment of the project features

No.	Mission	Economic sustainability	Environmental sustainability	Social sustainability
1	Create structure from new materials which made of plastic waste to be inflatable and replaceable	NA	✓	NA
2	The home can be assembled and disassembled according natural disasters and emergencies	NA	✓	✓
3	Climate change resilience and flood-proofing	NA	✓	NA
4	Dynamic expansion according to family growth and their location in the cluster	✓	NA	✓
5	Architectural sustainable technologies which are affordable and recycled	✓	✓	NA
6	Create recycled interior and exterior furniture for multi-purposes	✓	✓	NA
7	Responsive to global pandemics and emergencies like Covid-19	✓	NA	✓
8	Vertical farming inside courtyards to save area as a workspace	NA	✓	NA
9	Create spaces for education facilities and spread awareness	NA	NA	✓
10	Commercial and social activities for self-sufficiency	✓	NA	✓
11	Create local jobs to emphasize the inhabitants' role to sustain their life	✓	NA	✓
12	Sustainable infrastructure for buildings and irrigation system	✓	✓	NA
13	Water, wastewater, greywater, and waste management	✓	✓	NA
14	Sustainable technologies including renewable energy and human-made technologies to tackle the insufficiency of energy resources	✓	✓	NA
15	Affordable homes and facilities for slum dwellers	✓	NA	✓
16	Integration of Art and Culture with Architecture to shape the community's identity	NA	NA	✓
Total achieved		*10/16*	*9/16*	*8/16*

References

1. Duranton, G. (2015). Growing through cities in developing countries. *The World Bank Research Observer, 30*(1), 39–73. https://doi.org/10.1093/wbro/lku006
2. Ezeh, A., Oyebode, O., Satterthwaite, D., Chen, Y. F., Ndugwa, R., & Sartori, J. (2017). The history, geography, and sociology of slums and the health problems of people who live in slums. *Lancet, 389*, 547–586.
3. UN-Habitat. (2004). The challenge of slums: Global report on human settlements 2003. *Management of Environmental Quality, 15*(3), 337–338. https://doi.org/10.1108/meq.2004.15.3.337.3
4. Isunju, J. B., Schwartz, K., Schouten, M. A., Johnson, W. P., & van Dijk, M. P. (2011). Socio-economic aspects of improved sanitation in slums: A review. *Public Health, 125*(6), 368–376. https://doi.org/10.1016/j.puhe.2011.03.008
5. Shermin, N., & Rahaman, S. N. (2021). Assessment of sanitation service gap in urban slums for tackling COVID-19. *Journal of Urban Management, 10*(3), 230–241. https://doi.org/10.1016/j.jum.2021.06.003
6. OECD. (2020). *The territorial impact of COVID-19: Managing the crisis across levels of government*. Retrieved from https://www.oecd.org/coronavirus/policy-responses/the-territorial-impact-of-covid-19-managing-the-crisis-across-levels-of-government-d3e314e1/
7. Ramin, B. (2009). Slums, climate change and human health in sub-Saharan Africa. *Bulletin of the World Health Organization, 87*(12), 886. https://doi.org/10.2471/BLT.09.073445. PMID: 20454473; PMCID: PMC2789375.
8. Owusu, M., & Nursey-Bray, M. (2019). Socio-economic and institutional drivers of vulnerability to climate change in urban slums: The case of Accra, Ghana. *Climate and Development, 11*(8), 687–698. https://doi.org/10.1080/17565529.2018.1532870
9. FAO. (2022). *Country profile of South Sudan*. Retrieved from https://www.fao.org/countryprofiles/index/en/?iso3=SSD
10. Kuek, J. C., Velasquez, R. J., Castellanos, J., Velasquez, D. R., & Nogales, E. (2014). Hunger for an education: A research essay on the case of South Sudan and the voices of its people. *FIRE: Forum for International Research in Education, 1*(2), 22–31. https://doi.org/10.18275/fire201401021004
11. Briceno-Garmendia, C. (2011). *Sudan infrastructure: A continental perspective*. Africa Infrastructure Country Diagnostic (AICD) Country Report, World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/27270. License: CC BY 3.0 IGO.
12. Ministry of Foreign Affairs of the Netherlands. (2018). *Climate changes profile: South Sudan*. Retrieved from https://reliefweb.int/report/south-sudan/climate-change-profile-south-sudan
13. Rizzato, E. (2019). *100% recycled plastic tiles from Africa, Cold Harbour*. Italianbark.com. Retrieved 25 July 2022, from https://www.italianbark.com/recycled-plastic-tiles-africa-coldharbour/
14. Stauffer, N. W. (2011). *Solar cells printed on paper*. Main. Retrieved 25 July 2022, from https://energy.mit.edu/news/solar-cells-printed-on-paper/
15. Vortex Bladeless Wind Power. (2020). *How it works? – Vortex wind turbine in a nutshell*. Retrieved 25 July 2022, from https://vortexbladeless.com/technology-design/
16. Energy.gov. (2022). *Solar water heaters*. Retrieved 15 July 2022, from https://www.energy.gov/energysaver/solar-water-heaters
17. Jewell, C. (2018). *Pioneering fog-harvesting technology helps relieve water shortages in arid regions*. Wipo.int. Retrieved 10 July 2022, from https://www.wipo.int/wipo_magazine/en/2018/03/article_0003.html
18. Agroboca. (2022). *Groots urban farming*. Retrieved 31 August 2022, from https://www.agroboca.com/en/producer/groots-urban-farming

Part III
Technologies: Circular and Ecological Materials, Nature-Based Solutions for the Built Habitat

Low-Cost Procedure for Evaluating the Thermal Resistance of Building Materials

Alessandro Rogora and Paola Leardini

1 Introduction

Insulation materials are extensively used in building construction and the thickness of insulating layers has progressively increased in the last decades, mostly in response to mandatory energy performance and comfort requirements—even in Mediterranean countries with mild climates. Indeed, building insulation is effective in keeping both heated interior spaces warmer and air-conditioned spaces cooler. In 2021, the global building insulation sector was valued at US$ 28.38 billion and is projected to grow [1]. The rapidly increasing price of energy for heating and cooling, as well as the pressure to reduce CO_2 emissions of buildings to address the global climate change emergency have resulted in a shortage of insulation materials in the current construction market, with inevitable increase of prices; this high market demand makes it difficult to properly insulate buildings for a large portion of low-income population. On the other hand, it is difficult to replace expensive insulation products with natural, recycled, or upcycled materials due to their unknown thermal behavior, which would make any building energy performance evaluation unattainable. However, the use of local, natural, or upcycled materials would contribute to the reduction of both construction and demolition waste, and CO_2 emissions related to a product's life cycle, from extraction of raw materials to manufacturing, transportation, and landfill disposal [2]. This problem, and the associated environmental benefits, is even more relevant in developing countries, where

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certified insulation materials, with known third-party product specifications, are not commonly available.

One of the main barriers to the uptake of this *circular* approach to construction [3] is that using insulation materials with unknown energy transfer behavior makes it difficult, or rather impossible, to perform reliable energy simulations; however, the certification costs of these materials remain out of reach for private building owners, which hinders or even eliminate the possibility to use locally sourced, unconventional materials. To be commercially viable, the development of thermal insulation from natural or recycled materials remains confined in research laboratories with access to expensive testing equipments [4].

To promote do-it-yourself (DIY) building solutions that utilize local or unconventional insulation materials with good thermal properties, and to favor the use of recycled or upcycled products, it is necessary to develop and validate a simple, affordable, and quick procedure to evaluating the thermal performance of building materials. Addressing this need, the paper describes a simplified test method for the preliminary estimation of thermal resistance of an unknown insulation material with negligible thermal mass.

2 Conceptual Framework and Background

The scientific literature describes numerous testing methods to measure thermal conductivity of building materials, broadly grouped in two categories: steady-state and transient or non-steady-state methods, the former being simpler and considered more accurate for testing dry materials [5]. Three main types of steady-state measurement setups are available for the evaluation of thermal resistance of building materials or components: heat flow meter (HFM) [6]; guarded hot plate (GHP) [7], and hot box (HB) [8]. As a term of reference, the range of error expected when using the HFM method is between 1% and 15% [9]; however, due to the cost of the testing equipment, as well as the complexity of the procedure, all these methods remain out of reach for DIY builders, especially in developing countries where costs and technological delays are the main barriers to material certification.

A simplified testing procedure would help overcome these limitations. The methodology described in this paper is based on the assumption that, at steady state, there is a direct relationship between temperature difference between the two faces of a material layer and its thermal resistance. It also considers that, even for a single layer of material, a minimum of three thermal resistances must be included in the calculation of its total thermal resistance: that of the material itself, the internal liminal resistance and the external liminal resistance. It is therefore possible to evaluate the contribution of each of the three thermal resistances as a percentage of the total *R*-value by relating them to the measured temperature variation.

In this experiment, the thermal conductivity of sample materials was calculated according to the European UNI EN ISO 10456 [10], which includes a detailed description of the test procedure. According to this standard, the equivalent resistance of a building component already installed can be obtained using two thermocouples and a heat flow meter, with costs and a complex procedure that remains inaccessible outside the conventional construction market.

To address this issue, a quick and simplified procedure was developed at Politecnico di Milano to roughly estimate the thermal behavior of a building component or material with unknown thermal properties. The objective of the study presented in this paper is not to define an alternative certified procedure to assess the thermal properties of a material, but to give students, DIY builders and professionals, in particular those dealing with unconventional construction materials, the possibility to formerly evaluate the thermal performances of materials and components that are not commonly available on the market, such as papercrete, fiber adobe, multilayer reflecting insulation, etc. [11]. This preliminary evaluation through a steady-state procedure is considered acceptable for lightweight insulation where the effect of thermal mass is negligible [12].

2.1 Test Box Design and Construction

To achieve the steady-state assumed for the experiment, a cube test box with an edge of 600 mm and a missing side was built using a certified insulation material: 30 mm thick XPS panels (manufactured by URSA industries), with a conductivity λ equal to 0.034 W/(mK). High thermal resistance was achieved coupling two XPS sheets for each side of the test box, leaving one side open for the installation of the material to be tested. The five sides of the box, made of a certified material with known thermal properties, have been used as a reference in a preliminary test to evaluate the effectiveness of the procedure and the degree of error in estimating the thermal performance when using the proposed method. The missing side of the box was designed to accommodate the building materials or components to be tested while reducing the geometric thermal bridges in the corners (Fig. 1).

2.2 Experimental Setting and Testing Equipment

The test box was located in a conditioned room, maintained at a stable temperature of 25.2 °C, while the steady temperature inside the box was 46.0 °C, achieved using a 40-W incandescent lamp (Fig. 2). Both temperatures, inside the test box and in the conditioned room, were measured by means of temperature probes previously calibrated to give consistent results, with a difference between values measured by the two probes (in the range of 20–50 °C) equal or less than 0.1 °C.

To ensure stable conditions during testing, the system was turned on 12 h before measurements were taken. Data was collected in the early morning, with closed windows and rollers down to avoid direct solar radiation—to achieve and maintain

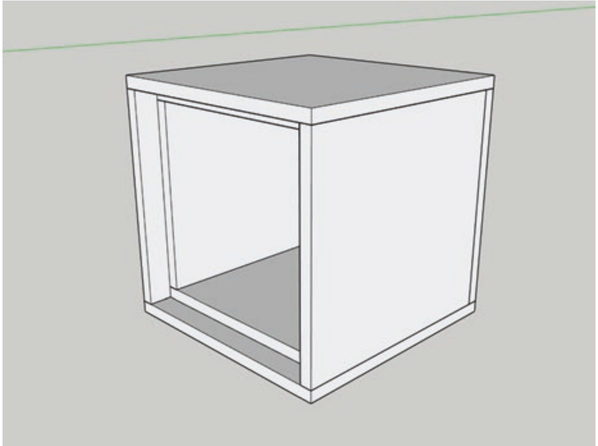

Fig. 1 SketchUp 3D view of the test box. SketchUp was used to minimize the number of panels to be used in the test box construction. The dimension of the box was determined according to the original XPS panel size (1250 × 600 mm)

a steady state. Surface temperatures were measured using a professional Raytek Raynger ST digital infrared pyrometer and a FLIR infrared camera (Fig. 4).

3 Preliminary Test and Evaluation of Thermal Resistance of a Certified Material

A preliminary test was performed to obtain the thermal resistance of the three vertical sides of the XPS test box with certified thermal properties, in order to verify the overall effectiveness of the system and its sensitivity. Based on the measured data of air temperature inside the test box (interior temperature = 46 °C), air temperature in the conditioned room where the test box was located (exterior temperature = 25.20 °C), and the exterior surface temperature of the XPS test box (26.60 °C), it was possible to roughly estimate the thermal resistance of the insulation layer and its conductivity, to validate the method by comparing calculated and certified values.

The difference between measured interior and exterior air temperature was equal to 20.80 °C (representing 100% of ΔT), while the difference between external surface temperature and conditioned air temperature was 1.40 °C (representing 6.73% of ΔT).

Assuming a direct relationship between temperature difference and thermal resistance variation, the liminal resistance of the vertical walls of the test box, which was assumed equal to 0.13 m^{2}K/W according to UNI EN ISO 6946:2018 [13], would represent 6.73% of the wall's total *R*-value. The thermal resistance of the wall was defined according to the same standard as the sum of two liminal resistances (each equal to 0.13 m^{2}K/W) and the *R*-value of the material layer:

Fig. 2 *Left*: View of the test box with the heating system on. *Right*: Thermometer used for the test

$$Rt = 0.13\text{m}^2\text{K} / \text{W} + R1 + 0.13\text{m}^2\text{K} / \text{W}.$$

As each of the two liminal resistances represents 6.73% of the total *R*-value of the test box wall, the thermal resistance of the XPS layer results equal to 86.54% of the total *R*-value. Using this percentage, it is possible to deduce the *R*-value of the 30 mm XPS layer to be 1.67 m^2K/W, and to calculate the thermal conductivity (λ) of the insulation based on the formula:

$$R = D / \lambda$$

Using this calculation method, the conductivity of the XPS layer was found to be 0,0359 W/(mK), with a difference of about 5% when compared to the λ provided by the manufacturer of 0.034 W/(mK). Such a difference can be considered acceptable for a preliminary, simplified assessment of the thermal performance of a building material.

4 Evaluation of Different Materials' *R*-Value

Having verified the effectiveness of the proposed method for the evaluation of the thermal performance of a building material, the following step of the experiment was to measure the *R*-value of a few different types of insulation. For the execution of the test, a frame made of 30 mm XPS, the same certified material the test box was made of, was used to hold in place five different insulation types to be tested:

- Multi-layer insulation ALUthermo QUATTRO (60 mm)
- Reflective insulation ALUthermo OPTIMA (60 mm)
- Rockwool insulation (40 mm)
- Phenolic insulation (40 mm)
- Expanded Polystyrene—EPS insulation (50 mm)

As shown in Fig. 3, two spacers made of a light polyethylene mesh were positioned on both sides of the ALUthermo QUATTRO and ALUthermo OPTIMA samples, to favor infrared reflection, with a finishing made of a thin layer of cardboard. Both multilayer assemblies had a total thickness of 60 mm.

The testing procedure was the same used in the preliminary test of a certified material (XPS); surface temperatures were first measured and then the *R*-value of the material layer obtained as a function of the temperature difference. Data measured (*T*) and calculated conductivity are illustrated in Table 1.

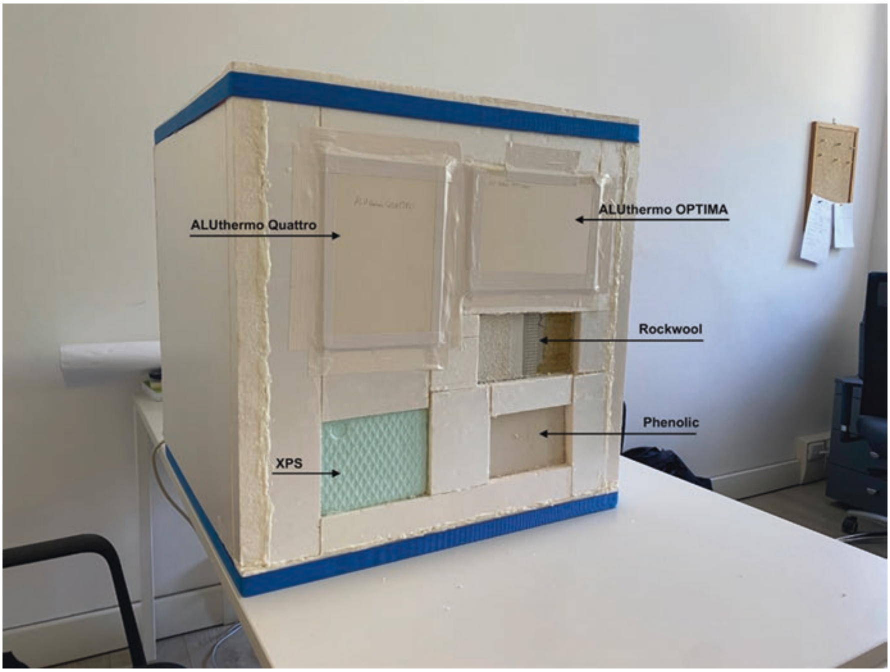

Fig. 3 View of the test box with the side frame holding five different material samples. The top and bottom blue stripes were used to tightly hold in place the front side of the box

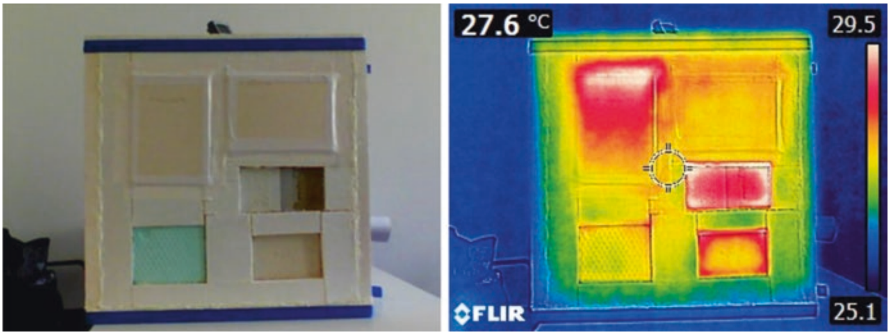

Fig. 4 *Left*: Side frame made of XPS containing the five materials samples to be tested. *Right*: the same shot taken with a FLIR infrared camera. The values of surface temperature were measured using both FLIR pointer (highlighting the value in the pointer) and the Raytek Raynger ST digital infrared pyrometer

Table 1 Results of the simplified test on five insulation samples

	Material	External Surface T (°C)	R-value (%)	Conductivity λ (W/mK)
1	ALUthermo QUATTRO	27.30	79.81	0.0584
2	ALUthermo OPTIMA	27.80	75.00	0.0359
3	40 mm Rockwool	27.30	79.81	0.0513
4	40 mm Phenolic insulation	26.39	83.65	0.0301
5	50 mm EPS	26.80	84.62	0.0350

5 Conclusion

Insulation is essential in building construction, both to fulfill performance requirements of national building codes and to reduce operational energy loads of buildings, which is imperative to address climate change; however, conventional insulation materials are not the only option, especially when in high demand and thus too expensive for low-income building owners and DIY builders. The use of locally sourced, alternative insulation materials and the reuse of upcycled materials can contribute to improving the thermal performance of buildings with a minimal increase of CO_2 emissions. This is even more important in developing countries, where conventional materials might not be available, or in case of DIY construction and renovation projects. A low-cost, simplified method to roughly estimate the thermal resistance of a building material or component offers the possibility to obtain preliminary, yet affordable, values of thermal resistance and conductivity that can be input into energy simulation software. This may favor the achievement of healthy and comfort indoor conditions even in low-cost and DIY buildings, and represents an important way to address climate change using passive strategies. Furthermore, the proposed testing method proved very effective for providing students, young researchers and professionals with an affordable and simplified tool for preliminary testing of innovative solutions for thermal insulation and to explore new, bio-based material options in building construction

References

1. Deadal Research. (2022, April). *Global building insulation market* (Report No. GC8B215A0A86EN).
2. McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things*. North Point Press.
3. Cheshire, D. (2019). *Building revolutions: Applying the circular economy to the built environment*. Routledge.
4. Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional sustainable building insulation materials. *Sustainable Materials and Technologies, 4*, 1–17.
5. Yüksel, N. (2016). The review of some commonly used methods and techniques to measure the thermal conductivity of insulation materials. In *Insulation materials in context of sustainability*. IntechOpen.
6. International Organization for Standardization. (1991). *Thermal insulation—Determination of steady-state thermal resistance and related properties—Heat flow meter apparatus use* (ISO Standard No. 8301:1991). https://www.iso.org/standard/15421.html
7. International Organization for Standardization. (1991). *Thermal insulation—Determination of steady-state thermal resistance and related properties—Guarded hot plate apparatus* (ISO Standard No. 8302:1991). https://www.iso.org/standard/15422.html
8. American Society for Testing and Materials International. (2019). *Standard test method for thermal performance of building materials and envelope assemblies by means of a hot box apparatus* (ASTM C1363-19). https://www.astm.org/c1363-19.html
9. Colagiacomo, C. (2021). Prestazioni energetiche dei material isolanti: Come misurarle, come verificare l'idoneità di rapporti di prova e schede tecniche. *Neo-Eubios, 76*, 26–36.
10. Ente Nazionale Italiano di Unificazione. (2008). *Building materials and products – Hygrothermal properties – Tabulated design values and procedures for determining declared and design thermal values* (UNI EN ISO 10456: 2008). https://store.uni.com/uni-en-iso-10456-2008
11. Rogora, A., & Lo Bartolo, D. (2013). *Costruire alternativo: materiali e tecniche alternative per l'architettura sostenibile*. Wolters Kluver.
12. Soares, N., Martins, C., Gonçalves, M., Santos, P., Simões da Silva, L., & Costa, J. (2019). Laboratory and in-situ non-destructive methods to evaluate the thermal transmittance and behavior of walls, windows, and construction elements with innovative materials: A review. *Energy and Buildings, 182*, 88–110.
13. Ente Nazionale Italiano di Unificazione. (2018). *Componenti ed elementi per edilizia – Resistenza termica e trasmittanza termica – Metodi di calcolo* (UNI EN ISO 6946: 2018). https://store.uni.com/uni-en-iso-6946-2018

Global Catastrophe: Climate Change Is Happening Now, Renewable Energy Can Reduce Its Impact

Ali Sayigh

1 Introduction

Since 1993, I, and many environmentalists, have been shouting that if we do not move to a low-carbon economy, then the changes in climate and global warming will happen much faster than any nation, or group of nations, can put right. The slow reaction from many industrial states has already resulted in various calamities around the world. High temperatures, some over 50 °C, have been recorded in Asia, Africa, South America and Australia. For example, in June 2022, the Municipalities in California closed schools and warned people not to go out due to the rise in temperature, which had reached over 40 °C. On May 17, 2022, Delhi temperature reached 49 °C [1].

In Italy the Marmolada Glacier, 3300 m high, reached 10 °C which caused it to melt and break loose, falling on hikers below causing death and disruption [2], see Fig. 1.

Also associated with climate change and global warming is unpredictable rainfall which causes flooding and loss of life, roads and buildings.

During the first week of July 2022, Sydney, the capital of Australia, had more than 3 days continuous rainfall, which resulted in a water rise of more than 80 cm. More than 30,000 people were evacuated, and so far, it has caused damage of more than 4.8 billion Australian dollars. The flooding phenomenon is known as La Nina, while severe drought is caused by El Nino [3] (Fig. 2). Both are casually linked to climate change.

Another impact of global warming is desertification of agricultural lands and lack of rainfall, which often gives rise to self-ignited fire in many parts of the world.

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Fig. 1 Avalanche disaster due to global warming in Italy

Fig. 2 Sydney rain flood during July 2022

At the time of writing, fires are rampaging in Spain and Portugal and Europe faces unprecedented high temperatures. In the USA, each year there are more than 3500 self-ignited forest fires, while in Australia such fires destroy more than 3,000,000 hectares per year, Fig. 3.

Fig. 3 Self-ignited fire in Greece in 2021 burned more than 25,000 hectares [4]

The recent IPCC (Intergovernmental Panel for Climate Change) COP26 was held in Glasgow, 2021; their findings can be summarized based on the BBC report [5]:

1. *Things are worse than expected*. 40% of the world's population is directly adversely impacted by climate change.
2. *Denial of historical responsibility* for carbon emissions because of fear off judicially imposed payments and compensation for damage to the environment and widespread adverse impacts, related losses and damages caused by fossil fuels and their associated industries especially in the world's most climate-vulnerable communities.
3. *Technology is not a silver bullet*. A warning that some renewable energy technologies could cause more harm than good. For instance, tree planting has to be carried out with scientific rigor and not randomly.
4. *Cities offer hope* but only if they legislate for renewable energy, greener transport and sustainable buildings.
5. *The small window is closing fast*. The elephant in the room is migration caused by desertification and rising sea levels. No amount of green energy and no number of electric cars will solve the problems of drought or flooding, as well as the excessive use of motor cars as in Fig. 4.

The drought in Somalia has seen thousands of families being displaced from their homes while livestock losses have been huge, see Fig. 5.

It is not just about spending on green energy and electric cars, investing in education, health systems and social justice could help people to cope with the impacts of rising temperatures. There must be investment in education, health systems and social justice to ensure that all countries have the means to cope with climate change.

Fig. 4 Congested city

Fig. 5 The tragedy of desertification

"Nature can be our saviour," said Inger Anderson, the head of the UN Environment Programme "but only if we save it first."

In order to achieve zero emissions there must be a concentration on advancing renewable energy technologies and ensure that production and, importantly, availability is distributed equally to all countries and not focused in a few hands. Governments and industries must not pay lip service and make promises to reach zero emissions by 2050 by which time it will be too late to meaningfully slow climate change and global warming.

2 The Use of Renewable Energy

Although renewable energy applications represent one side of the solution, the other side that must accompany it is to address energy efficiency and to significantly increase material recycling, to rethink transport strategy and reduce waste in industry. The public must be educated to rationalize and control electricity consumption. Investors must be encouraged to make large-scale investment in green technology, and agricultural policy has to ensure minimum waste and low energy consumption. However, clean electricity from clean sources has reached over 38%, which is higher than any other electricity generating sources.

Obviously, all renewable energy devices incur some embedded energy during manufacture, which result in CO_2 emissions. In this regard, wind energy is the best of them, Fig. 6.

3 The Use of Photovoltaic Technology

There is a long history of PV development dating back as far as 1839. By 1969, silicon cells had only achieved a 6% efficiency, which has now reached 20%, Fig. 7 [6, 7].

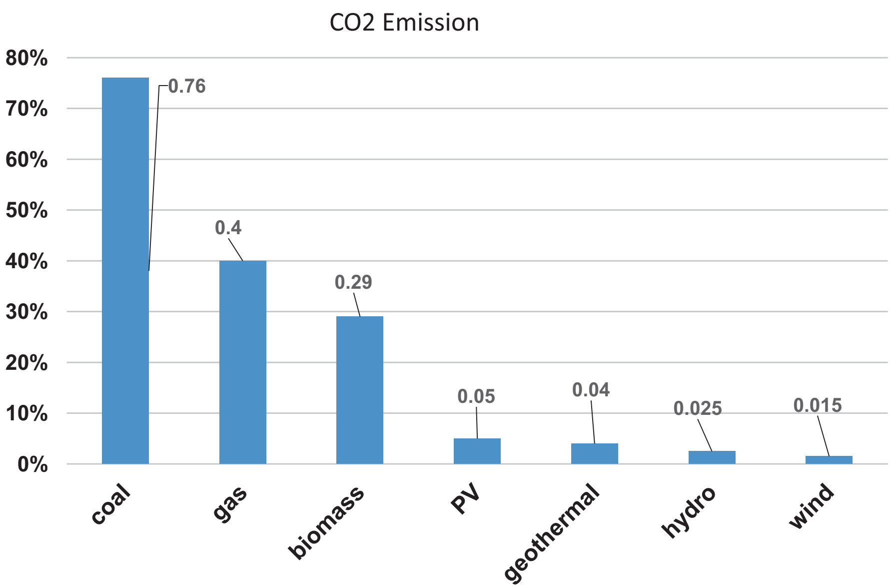

Fig. 6 CO_2 emission and embedded carbon of all power generation sources

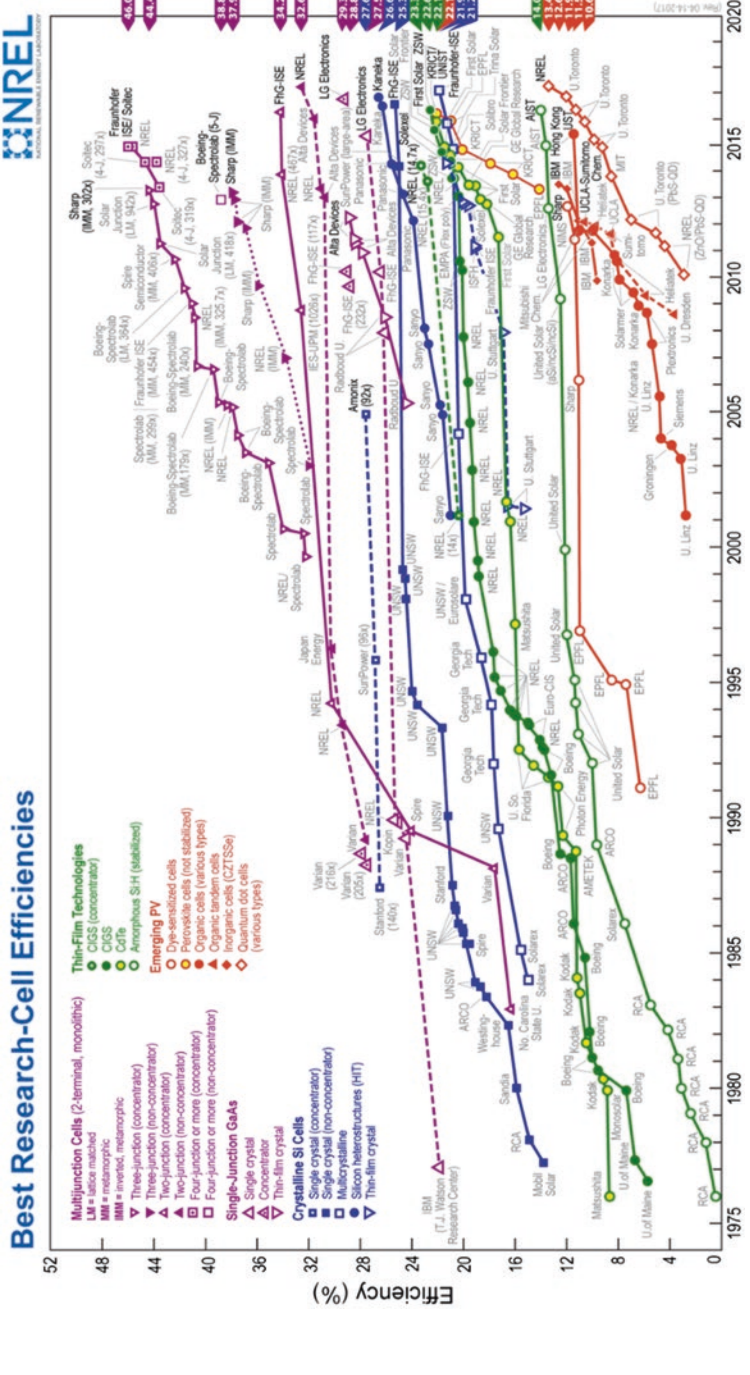

Fig. 7 NREL chart for best research—cell efficiency up to 2020

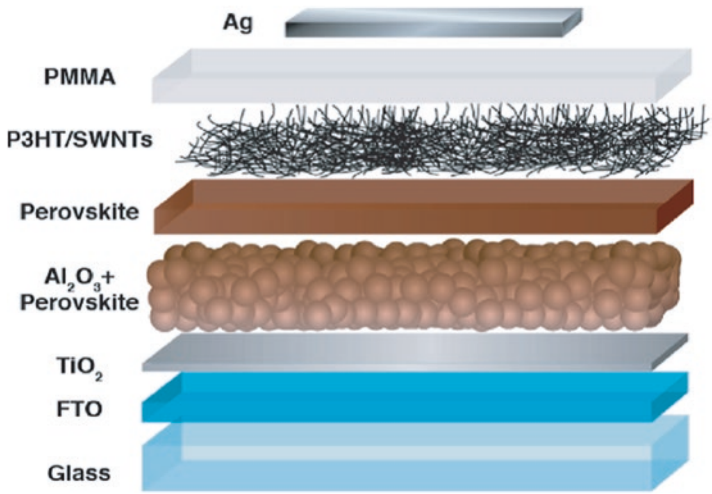

Fig. 8 The structure of Perovskite Cell, FTO is fluorine-doped tin oxide

An important advancement is the use of *Perovskite Cell* with an efficiency of 25%. Research into this type of cell is being undertaken in the USA, Germany and Australia and it is hoped that an efficiency closer to 30% will be achieved in a few years' time. Figure 8 shows its structure [8].

Meanwhile the dominant cells are the crystalline silicon cells, both mono and poly crystalline. Presently, many countries are trying to increase their share of PV application in the built industry and on rooftops. Several innovative applications and large-scale PV application have been installed around the world. A study by Global Data, February 2022, shows the size of rooftop PV and their prices up to 2030, see Fig. 9 [9].

Globally, there are many large projects for electricity generation as well as a multiplicity of small-scale local installations (Figs. 10, 11, 12, and 13):

While flexible PV can be used on cars and buildings with innovative façade designs.

In Europe in the German Bundestag has recently passed several Renewable Energy laws to install 400 GW of PV by 2045, 88 GW by 2024, reaching 128 GW by 2026 and 215 GW by 2030.

To encourage rooftop PV applications, FEED-IN Tariffs were introduced. Germany has recently reintroduced this concept and doubled the incentive offered, for systems up to 10 kW, (13.61 ¢) will apply over a period of 20 years, twice as much as before of (6.34 ¢); the tariff will be gradually reduced to (8.23 ¢)for systems up to 1 MW [11].

Another important use of PV is to cover reservoirs, lakes and shallow seas with devices. The following examples show how effective are PV floating systems (Figs. 14 and 15):

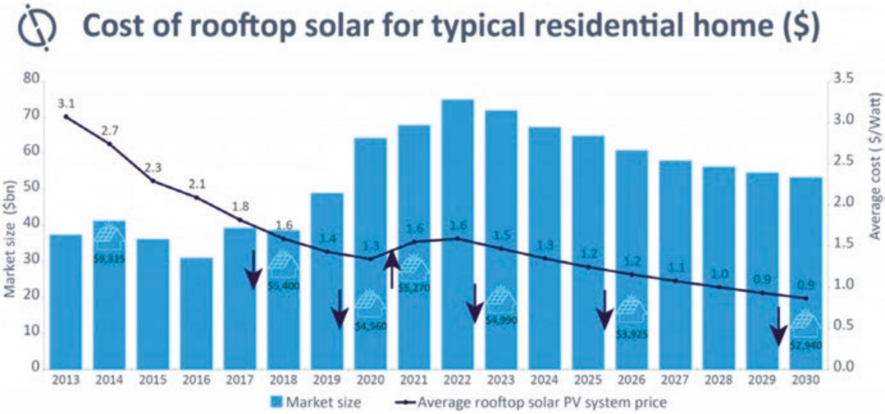

Fig. 9 Global Data, Oil & Gas Intelligence Center, February 21, 2022

Fig. 10 Rajasthan 8, built by Azure Power Global Limited (APG), 300 MW solar project in 2022. At (¢3.34) per kWh for 25 years, commission in 2022

A more recent development is to use PV to power motor cars: a good example is that of the Mercedes Benz research model shown in Fig. 16.

The battery pack stores nearly 100 kWh of energy. The car has a maximum speed of 140 km/h and uses less than 10 kWh/100 km and can cover 1000 km on a single charge. 117 solar cells feed the electric system and provide up to 25 additional kilometers. *Presently it is too expensive to market.*

Fig. 11 Saudi Arabia 700 MW at Ar Rass in Al Qassim province. ACWA Power will sell the energy produced to the public during 25 years. The project cost is $450 million

Fig. 12 Solar power canopies over California 4000 m canals could show a savings of 63 billion gallons of water annually, while 13 GW of solar panels could be installed and ready by 2024 [10]

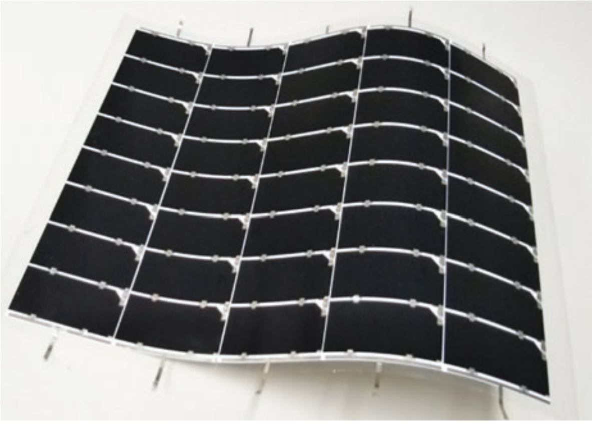

Fig. 13 Sharp has achieved 32.65% in their flexible solar module using triple junction cells. The PV module size was 31 × 31 cm, or an area of 965 cm^2 and an output of 31.51 W. (Ref: PHOTON Newsletter, June 9, 2022)

The PV instalment per year globally at the end of 2021 and the predicted of 2022 are shown in Table 1.

The Cumulative installation by the end of 2021 was *940 GW*, [14].

The cumulative PV installation by the end of 2021 was 940 GW.

4 Wind Energy Technology

Wind energy has progressed more than any other form of renewable energy. By the end of 2021, the installed capacity reached 824.874 GW. The number of countries with more than 1 GW installation is 38; there are ten with 10 GW. Only two countries have installed more than 100 GW, namely China and the USA [16] (Table 2).

Wind and solar power are producing more than 10% of global electricity at the end of 2021 [17].

The worldwide offshore wind capacity has reached 48.2 GW, more than 20% of which is in the UK. By the end of 2021, the capacity of fully commissioned sites in UK reached 11.3 GW. Offshore wind in UK generated enough electricity in 2021 to supply 33% of total electricity generation to 9.3 m to UK homes.

While Europe may be losing its dominance of offshore wind capacity to Asian countries, it is the predicted that offshore wind capacity in Europe will reach 102.6 GW by 2030. See the pie chart in Fig. 17 [18].

Fig. 14 25 MW Floating PV project in Andhra Pradesh, India, operational since August 2021, supplying electricity to 7000 homes. It uses 100,000 PV Modules. It saves 46,000 tons of CO_2 each year and 1,364,000 m^3 fresh water [12]

Fig. 15 145 MW CIRATA Floating PV Plant in Indonesia. The largest in Southeast Asia. It is supplying electricity to 50,000 homes and save 214,000 tons of carbon emission per year [12]

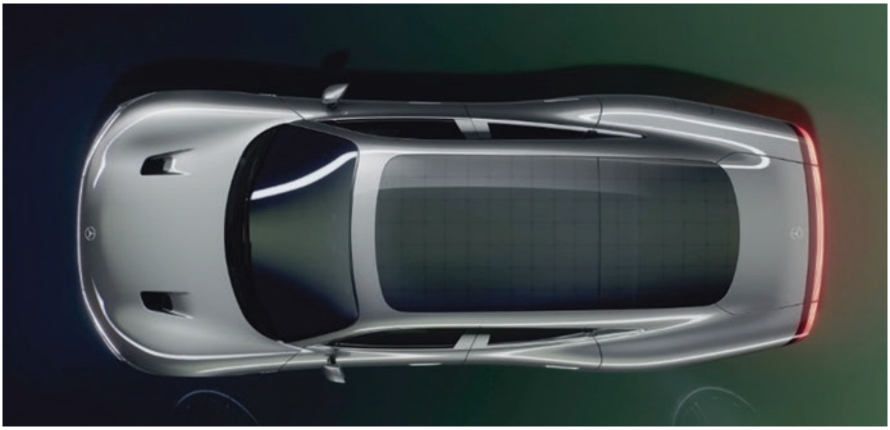

Fig. 16 Combined PV and electric battery car by Mercedes Benz [13]

Three major companies dominate the wind industry: the *Ming Yang*, *Vestas and Siemen* all of which have proposed very large machines since 2021. Vestas has built a 15 MW turbine in 2022, which claims to provide electricity to more than 13,000 British homes. Ming Yang, in 2021 has already built an even more powerful turbine of 16 MW, see Fig. 18.

Siemens Gamesa has a 14 MW turbine, which has rated power of 15 MW. They stated that a single offshore wind farm can now power a million homes. However, Vestas pointed out that such large turbines need larger harbors, larger vessels

Table 1 PV installment by 2021 and 2022 [15]

Region	China		United State		Europe		India		ASEAN	
GW	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
GW	157	226	56	65	87	96	32	38	8	10
Total 2021	340									
Total 2022 Pred.	435									

Table 2 The ten countries that had maximum wind power in 2021

No	Country	GW	No	Country	GW
1	China	328.973	8	France	18.676
2	USA	132.738	9	Canada	14.304
3	Germany	063.760	10	Sweden	12.080
4	India	040.067	11	Italy	11.276
5	Spain	027.497	12	Turkey	10.607
6	UK	027.130	13	Australia	08.951
7	Brazil	021.161	14	Netherlands	07.801

required to carry huge turbine components offshore, not to mention the high investments required to get to that point without a guarantee of a resulting high income, while Siemens stated they are more efficient in terms of installation time and cost—clearly, for 14 MW turbine you need one base structure and set of cables versus two for a pair of 7 MW machines. Soon there will be 20 MW machines in offshore farms.

Presently the most common machines in use are around 3 MW, such as the 430 MW Rampion off shore wind farm Brighton, UK, built in 2018 which generates enough electricity to power the equivalent of around 350,000 UK homes. This is equal to almost half of the homes in Sussex, see Fig. 19.

Also under development are floating turbines.

5 Hydropower Potential

Hydropower or hydroelectricity is the conversion of energy from flowing water into electricity. First used for mechanical milling and grinding grain. The demand for power rapidly increased turbine development and resulted in the creation of large-scale hydro plants to produce electricity using turbines and generators. Generated hydropower is classified into three sizes: large (>30 MW), small (100 kW–30 MW), or micro (<100 kW) [21]. Large and medium hydro plants are classified into three types:

Impoundment facilities use a dam to create a large reservoir of water with turbine-generators at the outflow used to generate electricity.

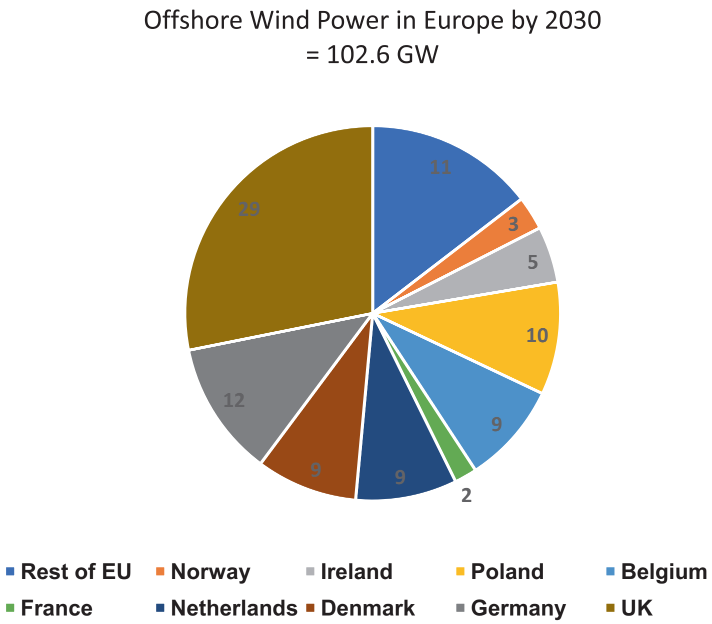

Fig. 17 Offshore wind power in Europe by 2030

Fig. 18 MingYang 16 MW turbine, 242-m diameter rotor, 118-m long blades, and a 46,000 square meter swept area equivalent to more than six football fields
It can generate 80,000 MWh/year of electricity enough to power more than 20,000 households
It will be fully operational commercially by 2024 [19]

Pumped storage facilities are similar to impoundment with the addition of a second reservoir normally built below the dam, water is pumped from the lower reservoir to the upper one to be stored and used at a later time.

Run-of-river facilities rely mainly on natural water flow which is from diverted a portion of river to flow through turbines. [21].

Fig. 19 Brighton, East Sussex, UK wind farm [20]

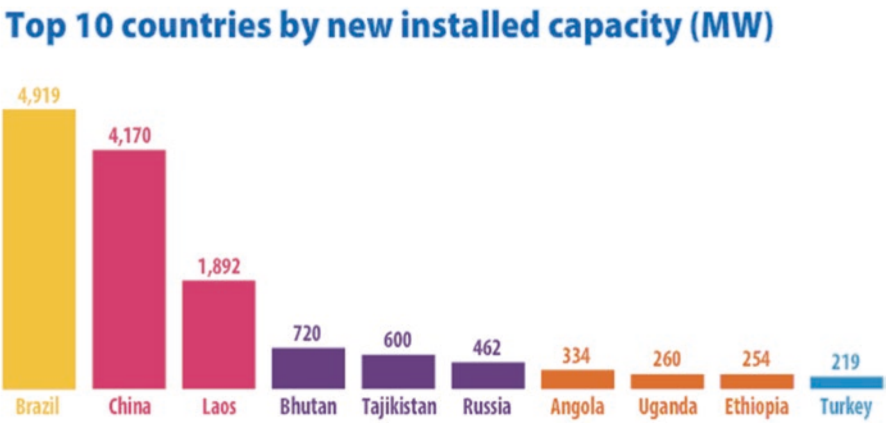

Fig. 20 The 10 highest hydropower providers in the world

According to the International Hydropower Association, global installed hydropower capacity has increased by 1.9% to reach 1360 gigawatts (GW) at the end of 2021. At present, it is the world's largest source of renewable electricity generation and is vital in reducing CO_2 emissions. Hydropower generators are found worldwide. China, India, and Brazil are expected to continue to increase their capacity [23].

Generally, hydropower generation was expected to rise by 3% per year until 2030. However, capacity expansion has been losing speed. This downward trend is expected to continue, due mainly to fewer large-project developments in China and Brazil, where concerns over social and environmental impacts have restricted them [22]. The 10 top countries with hydropower are shown in Fig. 20 [23].

6 Tidal Power

Tidal energy is produced by the surge of ocean waters during the rise and fall of tides. Various ways have been developed to generate electricity from the difference between high and low tide in areas where there is significant tidal range. Also, devices are used to generate electricity from the movement of ocean currents.

At present, this type of renewable energy is comparatively expensive, but costs are expected to decrease with more development and innovation. There are very few commercial-sized tidal power plants operating in the world. The first is located in La Rance, France, and the largest is the Sihwa Lake Tidal Power Station in South Korea. China, France, UK, Canada, and Russia all have significant tide potential [24]. The Rance Tidal Power Station is located on the estuary of the Rance River in Brittany, France. Its annual electricity generation is 500 GWh. Its length is 700 m. and the tidal range is 8 m (Fig. 21).

7 Solar Thermal Applications

The most effective way of using the sun is directly in heating. Solar water heater has been in use since the Babylonian times. In terms of solar radiation intensity globally, the Middle East and North Africa have the greatest potential for solar thermal applications, Fig. 22.

Fig. 21 Rance Tidal Power Station, Brittany, France [25]

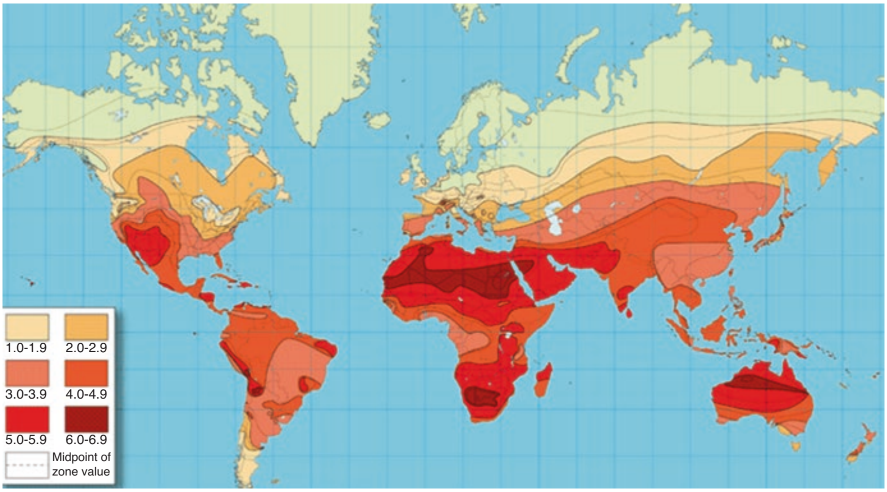

Fig. 22 Solar radiation intensity globally—kWh/m^2

Fig. 23 A typical central heating system installation [27]

Solar heating and cooling (SHC) systems have reached a total of 501 GW_{th} at the ***end*** of 2020, saving 43.8 million tons of oil and 141.3 million tons of CO_2 [27]. Apart from domestic hot water systems, using mostly evacuated tube collectors, the concept of district heating systems has been increasing globally, Fig. 23.

A rapidly increasing application is to use photovoltaic for both electricity generation and heating, Fig. 24.

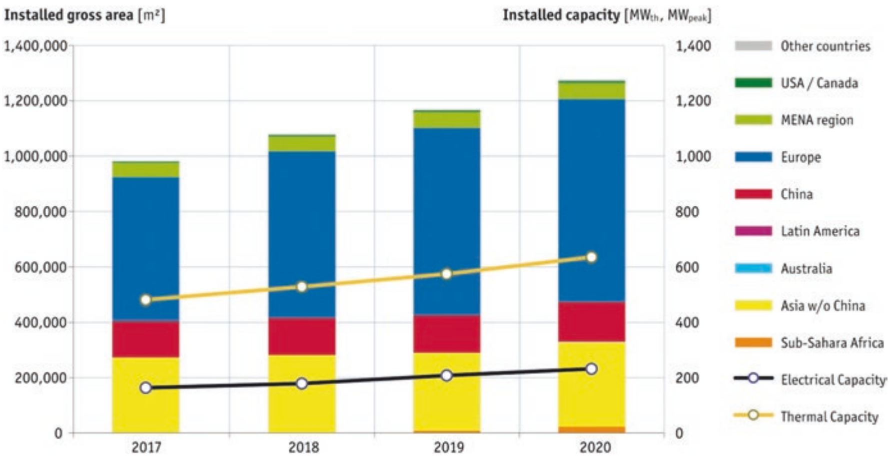

Fig. 24 The use of PV for electricity generation and heating [27]

8 Geothermal Energy

Geothermal energy is the tapping the earth's heat at different depths. Shafts are drilled at different depths, the deeper the shaft the hotter the layer of earth reached. It is estimated that 42 million MW of power flows from the earth's interior, primarily by conduction. The utilization of ground heat in the form of steam or hot water obtained through the circulation of water through shafts and tunnels by high-pressure pumps can then be distributed through a network of pipes on a district scale. This is an inexhaustible supply of energy flowing from the center of the earth [28].

The total installed *geothermal* power generation capacity at the end of 2021 was 15,854 MW, which is an increase of 246 MW over 2020 [28]. Figure 25 illustrates the top 10 geothermal power producers.

9 Biomass and Biogas Technology

Biomass is the utilization of agro products, mostly wood and agriculture waste as well as sewage refuse and domestic solid waste to be fermented either by anaerobic digesters or by chemical fertilization producing methane and other gases. At present, most animal and human waste is incinerated to produce energy or CHP. This can lead to a significant reduction in landfill of waste. Care has to be taken to ensure that agro products and wood chopping does not lead to deforestation or at the cost of food production (Fig. 26).

According to IEA [29], power generation from biomass at the end of 2019 was 68.5 GW, and at the end of 2021, it approximately reached 75 GW, and it is expected to reach 137 GW by 2030.

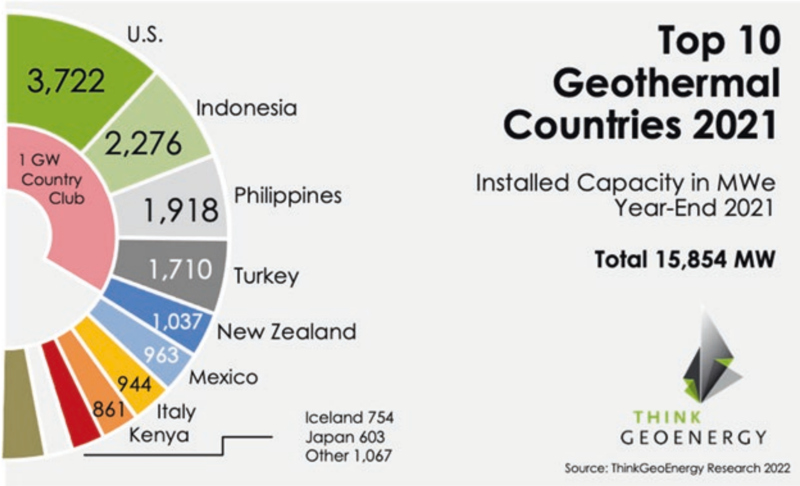

Fig. 25 Top 10 geothermal countries in the world [28]

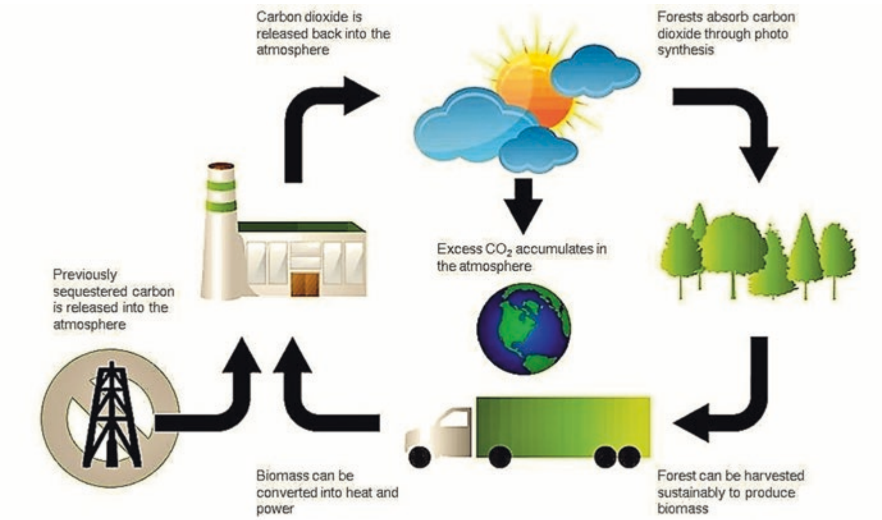

Fig. 26 Using wood and agricultural products for power and heating

10 Waste-to-Energy (W-T-E)

This is a growing technology due to the fact that as population increases more waste is produced. Recycling programs in most countries greatly help in the reduction waste rather, but care has to be taken that this does not result in merely shifting the problem elsewhere as in the shipping of waste to China and Turkey. Landfill is not a solution. Most countries prefer to use incineration process. As a rough estimate, the global W-T-E, power generation is 7 GW.

Fig. 27 Dubai WtE largest plant and Shenzhen—East largest plant with PV on top [30]

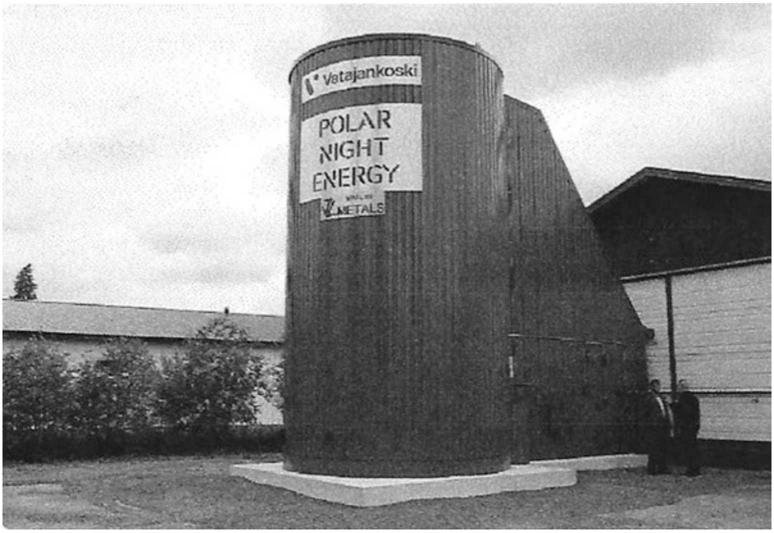

Fig. 28 Sand Heat Battery

The largest W-T-E plants are in Shenzhen, China and in United Arab Emirates—Dubai. They were both finished in 2020 and each plant can process 5500 tonnes of waste per day. The Dubai plant has a capacity of 185 MW, producing 2% of Dubai's annual energy consumption, while the Chinese in Shenzhen East has a capacity of 165 MW, handling one third of city waste (Fig. 27).

Although, we did not cover energy or electricity storage in this paper, it is worthwhile mentioning the below storage system:

Sand Heat Battery Research in Finland has shown that sand stored in silos can keep its temperature high for a very long time.

Polar Night Energy and Vatajankoski, an energy utility in Western Finland, have built a storage system that can store heat in the sand as in Fig. 28 [26].

Since sand is a cheap commodity and the silo battery is cheap to erect and maintain there is expected to be a great deal of interest in this form of storage.

> Around 100 tonnes of builder's sand, piled high inside a dull grey silo. It is cost-effective way of storing energy for when it is needed most. Sand is a very effective medium for storing heat and loses little over time. The developers say that their device could keep sand at 500C for several months. Circulating air through it then the battery discharges the hot air which warms water for the district heating system which is then pumped around homes, offices and even the local swimming pool. [26]

In the US NREL is working on a similar concept.

11 Conclusions

It is encouraging that renewable energy is continuously increasing in use by more than 9%. Presently 38% of the world's electricity is being generated from renewable energy. If we add all power generated from renewable, by the end of 2021, it is:

PV = 940 GW; Wind Energy Application = 824.874 GW; Geothermal power = 15.854 GW; Solar Thermal Applications = 501 GW_{th} at 50% the electrical power = 250.5 GW; Biomass and Biogas as well as W-T-E = 82 GW; Hydro power = 1360 GW. The total is *3573.228 GW*. Our figure shows an increase of 10.1%. However, ARENA figure was by the end of 2021, global renewable generation capacity amounted to *3064 Gigawatt (GW)*, increasing the stock of renewable power by 9.1% [31].

References

1. https://www.telegraph.co.uk/global-health/climate-and-people/delhi-records-highest-ever-temperature-49c/, 14 May 2022.
2. *The Guardian*. (2022, July 5).
3. Whiteman, H. (2022, July 5). *CNN*.
4. Angelos Tzortzinis/AFP/Getty Images.
5. McGreth, M. (2022, March). BBC report Science & Environment: Climate change: Five things we've learned from the IPCC report. *BBC News*.
6. Treble, F. C. (1991). *Generating electricity from the sun* (Renewable Energy Series; A. A. M. Sayigh, Editor-in-chief). Pergamon Press.
7. Sayigh, A. (Ed.). (2017). *Photovoltaics for sustainable electricity and buildings*. Springer.
8. Ansari, M. I. H. (2018). Frontiers, opportunities, and challenges in perovskite solar cells: A critical review. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews, 35*, 1–24.
9. Globaldata. (2022, February 21).
10. Photon Newsletter. (2022, February 11).
11. Photon Newsletter. (2022, July 11).
12. Hydropower & Dams2021245Hydropower & Dams, 24, 5, 2021.
13. Photon Newsletter. (2022, January 5).

14. https://www.google.com/search?q=What+is+PV+Cummulative+installation+globally+by+end+of+2021&oq=What+is+PV+Cummulative+installation+globally+by
15. https://www.iea.org/reports/renewable-energy-market-update-2021/renewable-electricity
16. Wikipedia. (2022, July). *Wind power by country*.
17. Global Electricity Review 2022.
18. https://gwec.net/wp-content/uploads/2021/09/GWEC-Global-Offshore-Wind-Report-2021.pdf
19. https://www.offshorewind.biz/2021/08/20/mingyang-launches-16-mw-offshore-wind-turbine
20. Photo was taken by Prof Sayigh during WREN Seminar 2019 in Brighton.
21. https://studentenergy.org/source/hydro-power/?
22. IEA Hydropower, Tracking Report 2020.
23. International Hydropower Association. *2020 Hydropower status report*.
24. https://www.nationalgeographic.org/encyclopedia/tidal-energy/
25. https://en.wikipedia.org/wiki/Rance_Tidal_Power_Station
26. McGrath, M. (2022, July 5). Environmental correspondent. *BBC*.
27. https://www.iea-shc.org/solar-heat-worldwide-2021
28. Think GeoEnergy Reseach 2022.
29. Report 013, ISSN 1654-9406, Uppsala, Sweden.
30. Schmidt, H. L. (2019). *United Arab Emirates Government 2019*.
31. Arena Global Power Generation from Renewable Energy by end of 2021, 11 April 2022.

Use of Vegetable Materials for Temporary Structures and Infrastructures

Sustainable Design with Tensile Systems: Case Study in Guimaraes

Angelica Rocco and Dora Francese

1 Introduction

According to Sustainable Development Goals for the 2030 deadline, relevant targets are established in favor of the reduction of carbon emissions, for a number of activities, including those of the construction sector. Scholars as well as enterprises had provided upon time both researches and products aimed at testing and applying sustainable materials, technological solutions, and innovative methodologies employable for the transition within the practice of urban regeneration.

The multi-scalar approach implies an integration of various aspects, for example, the social involvement and destination, the anthropic and natural landscape, and the use of prime and second matter. As far as the former is concerned, human heritage is already recognized as included in the landscape by the shape of historical settlement, by means of the availability of social, cultural, and economic resources, and leads to the consideration of the public space as a place for physical relationships and ideas' exchange, as well as knowledge's, economy's, and practice's sharing: the latest perspectives find their own expression in the lightness and impermanence of systems, which conveniently answer to the dynamism of a continuously changing society.

The link between urban space and circular economy can be found through such a methodology for practice design approach, which can involve peculiar materials so as to ensure the reduction of CO_2 as well as to increase comfort and social welfare. One of the categories suitable for circular process in the construction sector can be recognized in the textile materials. In fact, they are appropriate for a number

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of reasons: the adaptation to multifunctional uses, the removability of the systems, and the potential of allocation in the public space.

Architecture of wide spaces, for both internal or external areas, is nowadays meant for heritage protection as well as social inclusion, both actions aimed at enhancing the public urban zones: textile structures are in fact one of the best technologies now existing and available for guaranteeing such performances.

In the public space, the building components designed for such structures are already efficient for a manifold of activities, when and if provided with appropriate contextualization to the climate.

The potential of these textile building components promotes the development of products, mainly those which are aimed at employing a few of matter, at processing a closed productive cycle [4], and at producing a low LCA value. One of these matters is recognized in an ancient vegetable substance, the hemp fabric, derived from the *Cannabis sativa* L. plant.

2 Sustainable Choices as Dynamism Glue

This paper deals with the idea that the sole glue for the dynamism of present society is identified with a sustainable strategic vision of place, which can answer to the public space's wreck [10] by defining appropriate methodology and technical solutions.

The main goal is then to trace the tensile structures as well as the organic materials as potential elements for new design paradigms.

The aforesaid glue can be effective if the attention were focused on the potential of links between various urban regeneration projects within the public space, in order to lead toward a number of issues emerging from new design approaches; the latest can be, for example, identified in the temporary architecture which assigns value to the natural capital so as to improve its protection and enhancement as heritage of the communities.

Therefore, any new strategic vision for transformation should go through the interpretation of the existing cartography as well as through the creation of new maps able to provide the right value to the indicators found in the different contextual places during the preliminary investigations.

The application of such strategies finds its potential in the practice of regeneration projects, when the main goal was that of sustainable and social efficiency of the action.

Certain locations can be specifically identified as appropriate ground for such experiments, where the functional reconnection of territorial system and the relative cooperations can be actualized by maximizing the aforesaid efficiency.

3 Methodology

One possible context, suitable to the required characteristics as case study for the application of the proposed strategy, has been found within the Urban park of Azurem in Guimaraes, Portugal (Fig. 1). Here a likely ecological corridor has the peculiarity of being partly disconnected and partly linked to the city, thereby providing a great potential for the naturality to become ecosystemic services [1–3] to anthropic use: the topographic characteristics of the place, in fact, provide nearness and easiness of facilities between city and nature, both suitable for supplying a real connection network.

The district in fact includes a double soul: on the one hand, it points toward the University campus, with a row of aligned trees, the library, and the parking for the university community. On the other hand, a spontaneous, natural, and disorganized little wood merges, beyond the bush coasting the little bordering river (Fig. 2), with the most attractive and touristic part of the city, that is, the Guimaraes Castle (Fig. 3).

The methodology of the research for investigating the potential of employing natural and cultural resources, and for testing the efficiency of tensile structures as temporary architectural components aimed at enhancing and requalifying the site, previewed a number of studies and deep analyses.

For example, by means of the oreography analysis about the location, a morphological link between natural biodiversity components and urban landscape has been made possible, so optimizing the various typologies of users' requirements, through the integration of design suggestions within the land. This could be possible by reactivating some paths already existing within the area, as well as by connecting the park itself with the historic external urban system.

Fig. 1 Campus of Azurem. (Edited by A. Rocco)

Fig. 2 Urban Park at the Campus of Azùrem (www.uminho.it)

Fig. 3 Guimaraes Castle (www.uminho.it)

Moreover, the climatic analysis had allowed to size the choices to be adopted and to evaluate eventual impacts (Fig. 4). The climate is warm and temperate in Guimarães; there is more rainfall in the winter than in summer; the average temperature is 13.5 °C. According to Köppen and Geiger, this climate is classified as *Csb* [9].

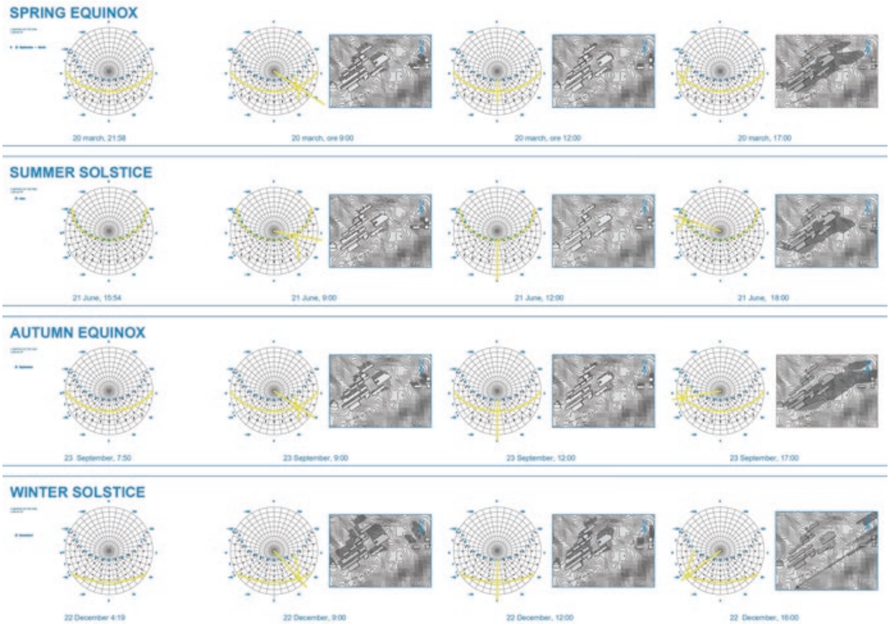

Fig. 4 Study of sunshine during the months of the year. (Edited by A. Rocco)

It was very important the studies about the noise processes during the day and the night, since in Portugal the Noise General Regulation (RGR) in force from 2007 is a strategic tool for analyzing and planning, which provides restrictions aimed at guaranteeing the quality of sound landscape and the promotion of a suitable distribution of various functions: residence, work, and leisure time.

Moreover, tracing the routes of cultural and historical interest and attesting the presence of buildings and public events occurring on that territory with the relative concentration of affluence all the year round (Fig. 5) allows to plan the modalities and the places where to strategically act for an efficient requalification. By comparing various results provided by the SWOT analysis (Table 1), the strength relationships, the weaknesses, the opportunities, as well as the hazards of the system could be identified thanks to the classic graphic representation: from the latest some strength points emerged such as the variety of flows as possible appealing elements.

The consequence of these analyses pointed out the need of applying a more fluid strategy with the installation of some temporary architecture, such as the *Palco de Verao* and the proposal of some repetitive and demountable Social Housing structures (Fig. 6).

This solution emerges from the design goal of adopting lightness and permeability: the building informally accommodates the guests through some crossing paths for pedestrians and a door, which works as a dialogue and fruition-of-the-site element between the involved subjects of the international Campus, the citizens, and the preexisting historical, cultural, and ecological presence (Fig. 7).

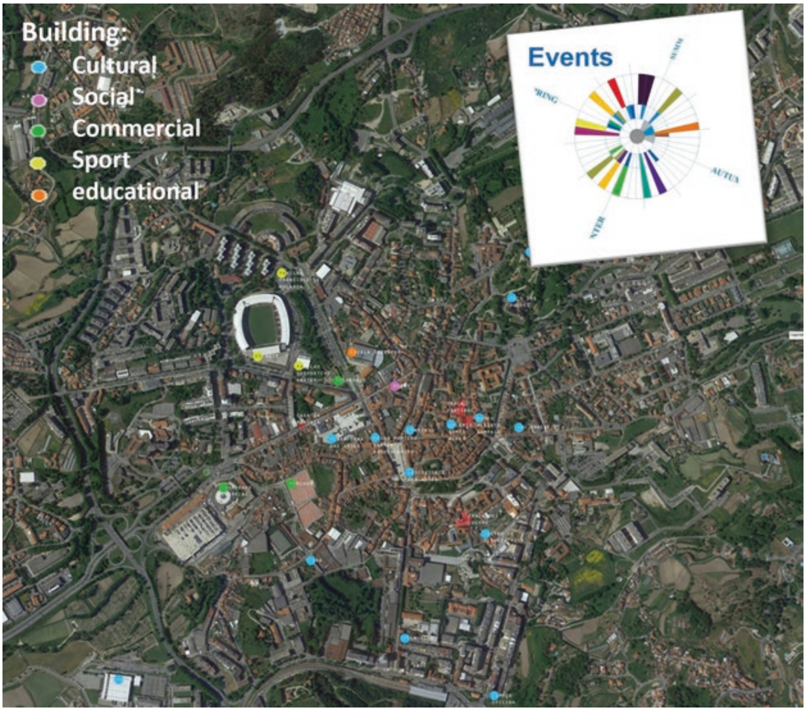

Fig. 5 Presence of buildings and public events occurring on the district with the relative concentration of affluence all the year round. (Edited by A. Rocco)

The graphical maps of the preliminary design project (Fig. 8) highlight the resulting conceptual address, which focuses on a light groundwork, by adopting such typologies that can lead to feelings of delicacy and unsophistication, clearly mentioning the idea of the tent. The material for the latest has, therefore, been chosen as the hemp, which had been in fact adopted already by the Romans in the *velarium.*

Many sustainable principles have been pursued within the design choices; for example, the strong link with the Park, of which the proposed functions become an integrant scene. The whole built system is shaped as an organism that finds the relative arrangements as elements for the respect of place and preexisting cultural presence. The new building develops as an aggregation of various pavilions, established on the area according to clear hierarchical and functional aligned systems.

The *Palco de Verao*, composed of four parts—entrance and coffee bar, central open area, facilities, closed auditorium, open auditorium—could allow both the management of the access flows to the structure and those connecting the city to the country, mainly highlighted by the open space with the pavilion which could generate community.

Table 1 SWOT analysis

Opportunities	Weaknesses	Strengths	Threats
Existing urban and extra-urban public links with parking at University entrance *Afonsina—Tuna de Engenharia da Universidade do Minho* City and University interaction Area of the old neglected racecourse Landscape values: river and two artificial lakes Connection to the Castle International and sustainable university	Private property in the neighboring Decay due to lack of maintenance Buildings to be recovered near the *rivo* Excessive sun exposure in summer Lack of adequate public lighting	University campus and historic center in the neighboring Great turnout of tourists and international students Flat topography with little accentuated height differences Various accesses to urban and extra-urban public transportation Preexisting routes Security and surveillance Excellent sun exposure in winter	Increase of uncontrolled flows from the city Homes close to the area River in some places deep and without parapets Neglected areas Presence of homeless people at night Lack of water inside the two artificial lakes

Edited by A. Rocco

Fig. 6 SWOT ANALYSIS. (Edited by A. Rocco)

The employment of biocompatible materials as well as those deriving from certified chains leads also to the selection of some peculiar products, for example, the hemp-steel system, which allows a number of benefits, such as the chance of keeping a structural lightness, the good response to seismic actions, the potential for covering wide spaces, the quickness of yard times, both in the mounting and demounting actions for even big structures, and easy maintenance thank to the easiness of substitution; finally they can guarantee durability and high architectural

Fig. 7 Masterplan. (Edited by A. Rocco)

quality, due to the fact that—following the flow of lime-and-hemp mixture—the built architectural element is quickly mounted and completed.

The external envelope has then been conceived as a skin: a system which breaths, able to adapt to the external climatic conditions, capable of favoring the muffling and the time lag of the daily thermal wave, improving the energy performances of the building by means of reduction of nonrenewable energy requirements.

The aforesaid reminder to the tent can be found also thanks to the employment of the hemp membrane, which defines unexpected and informal connections: in the *Palco*, the installations—along the facades—of a modular system rolling on a frame with membrane allow to shield the light within the closed spaces and to protect the outdoor central areas from the atmospheric agents. The rotation mechanism dictates

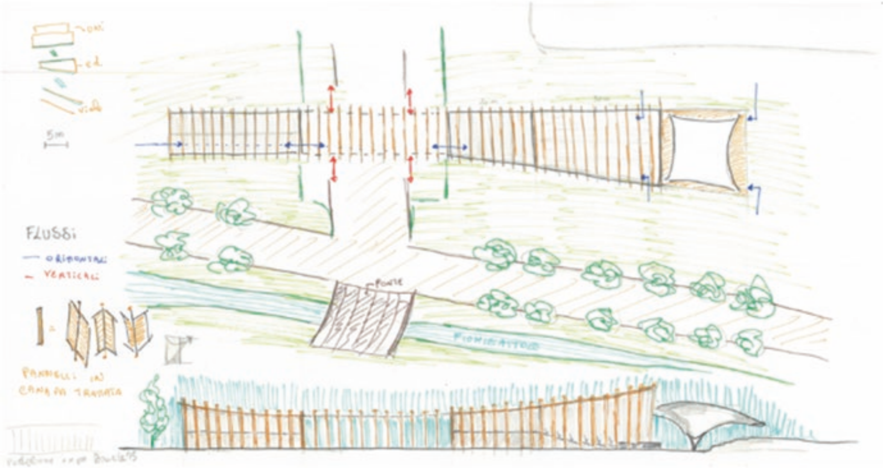

Fig. 8 Project sketches. (Edited by A. Rocco)

Fig. 9 Elevations of the preliminary design project. (Edited by A. Rocco)

new architectural configurations with a modular rhythm, in harmony with the indoor climatic perception. In the open auditorium, covered with a transformable and transferrable structure (the membrane), it is possible to benefit from the transfer itself as well as to create some domes for protecting the underneath audience in the stalls. Also in the Social Housing structures, some installations are previewed with some poles fixed on the ground (Fig. 9).

The proposed technological solution for temporary covering the open spaces is made up by means of a tensile structure in organic material (the hemp fabric). Moreover, the technical elements of the wall are proposed in hemp-and-lime bricks (Fig. 10).

A specific mention has to be provided for the use of hemp as a material to be preferred for a number of reasons; the cultivation reduces the CO_2 in the atmosphere and oxygenates the ground. Moreover, the employment of this prime matter in the construction sector could promote a reactivation of the local chains of hemp, leading to a significant cost reduction and an enhancement of the landscape fruition with farmed fields. Moreover, the production chain of hemp products can contribute to

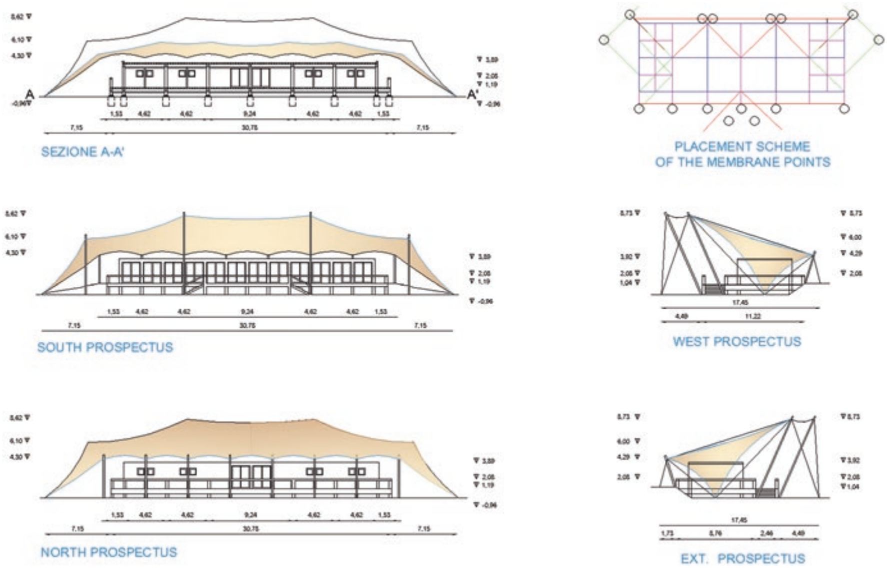

Fig. 10 Social Housing. (Edited by A. Rocco)

extract carbon dioxide from the environment. In the transfer from the shives of the hemp to the products in hemp and lime, the insulation properties, the soundproof performances, and a very high hygroscopicity are ensured.

Therefore, the project takes advantage of the aforesaid benefits so as to allow the envelopes to breath, and at the same time to guarantee a high degree of health in the air quality.

4 Conclusion

Today, the dynamics of a continuously teetering society require an increasing number of temporary architectures, adaptable, ready-to-use, and reversible [6]. These structures, the most advanced result of the lightness in architecture, reflecting the Mies' idiom *less is more*, have endured a strong acceleration with the experiments carried out by Frei Otto, the Archigram utopic projects, the Cedric Price's, and Massimo Majowiecki's works. Presently, in order to correctly designing in the field of the ultralight systems, a sound know-how is indispensable, which will allow to reach some formal freedoms with a very rigorous method.

In Italy, notwithstanding the temperate climate could support this kind of architecture, a few and only small constructions are completed, even though, just in Italy in 1968, a light structure had been built for linking the Exposition Palace and the new Pavillion of the Triennale in Milan (by De Pas, D'urbino e Lomazzi).

Another goal of the here presented research is that of demonstrating how necessary it were to accomplish design choices on temporary light solutions, for they incline toward a reduced consumption of material and economic resources, and ease the assembly and disassembly stages, also by nonspecialized personnel; moreover, these solutions employ dry setting up and non-deep foundations, and last but not least they allow the use of elements which are easy to be transported and replicable [8].

Very notable value can be attributed to the textile industry toward the ultralight architecture: from the heavy cotton elements on the external surface with impermeable products in the first interventions, then the fabrics employed in the structures of the 50s, originally used as filters for smokes and dusts in the factories, until the first polymeric fabrics, and finally the technical cloth with which the architecture are completed today.

Although lightness and thinness of the membranes define a very low thermal inertia in comparison with the conventional architecture and that the thermal insulation of the textile envelopes is also minimal, nonetheless, in order to reduce the external-internal thermal exchange, new solutions have been testing: the chance of employing natural luminescence allows a notable energy saving, as in the case of Zénith project by M. Fuksas [8].

The concept of temporary is moreover accompanied by the presence of a short industrial chain, where design and manufacture share tools and operators [10].

Since also the hemp can be included in the strategy of the circular economy, the two issues can be joined so as to demonstrate that it is possible to pursue the design sustainability through methods that will move firstly from the choice of materials.

The membrane envelope allows a diversified production of components, both industrialized and handcrafted, which are easily integrated within both the support structures and board components. By treating the membrane with the hemp, the wastes from the production could be re-employed for manufacturing other construction materials, such as bricks or panels.

An appropriate design procedure, joined with a suitable management of the environment and landscape, could guarantee value to city upon time; the city context, as a general conceptual frame aimed at inspiring the links between man and nature, can return significance to the place through very light architectural solutions.

References

1. Carpenter, S., Bennet, E. M., & Peterson, G. D. (2006). Scenarios for ecosystem services. *Ecology and Society, 11*, art29.
2. Chan, M. A., Atterfield, T., & Glodstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics, 74*, 8–18.
3. Fisher, B., Kerry Turner, R., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics, 68*, 643–653.

4. Francese, D. (2017). Innovative and sustainable use of natural materials in the Mediterranean basin. In D. Francese & A. Passaro (Eds.), *Building in the Mediterranean region. Sustainable technologies and materials for inhabiting: Italy, Morocco, Portugal, Tunisia*. D'Arco Editore.
5. Kronenburg, R. (2014). *Architecture in motion: The history and development of portable building*. Routledge.
6. Martinotti, G. (1993). *Metropoli, the new social morphology of the city*. Il Mulino.
7. Mazzola, C., & Liuti, A. (2018). Temporariness of textile architecture a comparative study on innovation. *AGATHÓN, 4*, 195–202.
8. Monticelli, C., & Zanelli, A. (2018). Structural membranes in architecture: An eco-efficient solution for the future? *TECHNE – Journal of Technology for Architecture and Environment, 16*, 235–246. https://doi.org/10.13128/Techne-23041
9. Peel, N., & Finlayson, B. L. (2007). Updated world map of the Coppen-Geiger climate classification. *Hydrology and Earth System Sciences, 11*(5), 1633.
10. Zanelli, A., & Campioli, A. (2009). *Textile architecture designing and building membranes and bodies* (pp. 1–159). Il sole-24 ore. ISBN: 9788832474046.

Green and Healthy Solutions in Post-pandemic Housing

Fabrizio Amadei, Giada Romano, and Marco Giampaoletti

1 Introduction

In the post-pandemic period, one of the priorities will be to rebuild a vision of the future in a shared and participatory way [1]. It starts with the image of the future that we have at this moment and by intentionally thinking about a better future to achieve it by some necessary steps [2]. After the pandemic, there has been a reduction and confinement of human activities in living spaces [3]. On the other hand, the pandemic has strengthened the evidence of a crisis in the environmental, social, and economic model that has become no longer sustainable “manifesting itself in multiple interconnected crises” [4]; so it needs to replay to the climate change, the migrations, and the growing inequalities that increase the complexity to give answers. Although the IPCC reports continue to provide a global assessment of the commitment to mitigate climate change, it is clear that there is a lack of real impulse and acceleration of the commitments to reduce global emissions by countries. In addition to a global scale act, it is glaring that with the post-pandemic, in particular at the scale of cities and districts, the environmental regeneration is basic to obtain positive effects, even at the scale of the single building [5]. The design of the intermediate spaces can give a start to processes that regulate positive emotions such as appraisal (situations assessment) and coping, that is meaning to identify resilient characters and protective factors to contrast the everyday life criticalities and problems in case of just a pandemic emergency as a post-pandemic phase.

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2 Resilient Responses in the Post-pandemic Through the Implementation Tools of the PINQua and the PNRR

After a lengthy period of social and environmental spacing, the physical and mental need requires a phase of cognitive relearning, to reactivate all those emotional and cognitive processes through the restoration of smart relationships. At the same time, this determines, on the one hand, increasing more flexible and multifunctional houses and, on the other hand, opening up to social gathering through in-between spaces. Therefore, it is also necessary to redefine those interconnections between the environmental system and the technological system: in this framework aimed to health, the green actions in intermediate and in-between spaces can be a reference as recreational, social, and productive functions. In "The Cognitive Benefits of Interacting with Nature" [6] it can be investigated how the interaction with nature reintroduced into the urban environment, has positive effects on well-being and cognitive functions. In particular, it has some effects on attention and memory, and therefore directly environmental behavior also. On the other hand, Erich Fromm defines biophilia, which literally means "love for life," as a link of the interaction with nature, just like as an attraction that cannot be ignored. In the new ways of social regeneration, after a city built "by projects" in which the plan is a unifying and shared element and subsequently the affirmation of a model of "dispersed city" [7], "it has emerged a new generation of urban actors able to frame their own business vision combining the use of fixed territorial capital on the public, the creation of social value, of economic circularity, that hold the skills to intercept and to access at various public funding, to use innovative financing tools, to have access at credit by ethical finance tools, to manage, to transform, to redevelopment urban and, finally, a new welfare model" [8]. In Italy, the new current scenarios do not highlight unitary strategies in a characterized framework by uncertainties, but they find a partial, sometimes generic, sometimes punctual, response to the changes in place by tools such as the National Innovative Program (PINQua), promoted by Ministry of Sustainable Infrastructure and Mobility (MIMS). It initially provided for a fund of 400 million euros to which was added with the complementary fund of the PNRR, 2.8 billion euros. The aim is building new public housing to regenerating degraded areas through sustainable and inclusive interventions, to be carried out without the consumption of new soil "do not significant harm, DNSH" (Next Generation EU). The National Recovery and Resilience Plan (PNRR) is also significantly boosting urban regeneration. Two projects placed in the Roman area will be examined below: the first is the redevelopment of a bonded building in Porto Fluviale that is one of the three proposals, admitted for funding, of the Municipality of Rome. It could be taken into consideration just for the fabric of the city in urban regeneration, as the need for transitory housing, such as that of the university population, transforming it from problem to resource [9]. In this case, Porto Fluviale can be imagined as the place of the "Circus…. Indispensable, indomitable, irreducible, it is precisely the contradiction that we feel as a need: a place able to perpetuate its otherness while maintaining high tension without leading to conflict. If it would homologate to the city, it would lose its regenerative energy, its charge of provocation, stimulus innovation" [10]. Transversely to participatory paths, citizens ask the in-between places that could be more open and more aggregative, especially toward young people and families. In collaboration with other social realities and subjects of the territory, these ones can promote territorial garrisons to perform a dual function, just educational as cultural, such as to be able to be a point of reference and aggregation for the entire district or eco-district and for the most vulnerable social groups [11]. All forms of green systems must have a significant role in design, representing a strategy aimed not only at decarbonization but also at health.

2.1 PINQua: Porto Fluviale RecHouse, Design Examples

Municipality of Rome, Redevelopment of a bonded property and recovery of the 53 occupying families from 21 different countries Project: Arch. Valentina Cocco.

Porto Fluviale is one of the three areas of the PINQua selected by the Municipality of Rome [12, 13]. Located in the Ostiense district of Rome, its objectives are an architectural recovery of a bonded property without soil consumption, in a sustainability and densification way through a re-functionalization of the indoor and outdoor spaces. Currently it is a former barracks bonded and occupied by nomads and homeless, declared as an asset of historical and artistic interest by Mibact. The intervention allows an increase in the social housing stock (ERP) and a reduction in deprivation housing of the 56 families, coming from 13 different countries, which are occupying the building but also as a process of social inclusion and urban welfare through innovative management methods. (Prototype of intercultural coexistence condominium). The participating project leads from a collaboration with the faculty of Architecture of RomaTre and Luiss contributed as specialist consultancy but also as a regeneration of the socioeconomic fabric and a restoration of safety of the places. The regeneration passes through the increase of the social "mixitè," understood as a category of public action of urban policies to enhance the social proximity between heterogeneous groups, but also in sharing a new public space with the neighborhood. In this case, the internal courtyard becomes an open square. Social and collective functions are also greatly increased through the activation of an energy community linked to the photovoltaic roof garden but also with an anti-violence counter (low-threshold counter for women victims of violence), civic and intergenerational collective uses, such as an integrated playroom and services for the elderly, and technological-digital for distance learning classrooms, reskilling, and coding. The functions currently present are confirmed and implemented just like spaces and surfaces, such as those for crafts, for circus training (called Circofficina) and for learning to dance, a tearoom, a weekly market at Km 0 and a place for sustainable mobility by the link with the bicycle lane. The project, built in the early twentieth century, as a bound historical-artistic asset, confirms the shape and the existing structure in reinforced concrete and tuff masonry. In this case, the use of the Francois Hennebique's system, in which the connections between the reinforcements collaborate as in a ribbed slab, was an innovative structure for the time, so the interventions are being aimed to not altering the nature of the building, confirming the original technological character in the reconstruction. Therefore, the project provides for a restoration of the property and at the same time for its recovery as a restricted public property for which the regional laws of Lazio establish different parametric costs in the case of ERP interventions. The strategy aims to increase neighborhood ties but also the proximity of existing services, while the transport in the area is well connected just for vehicular traffic, including the public transport, as for position between two railway stations. On the contrary, it misses to be reconnected to the viability for sustainable mobility created up to the edge of the neighborhood, although the Urban Sustainable Mobility Plan (PUMS) provides for the construction of bicycle lanes. If on the one hand the project is part of a consolidated city fabric that does not require new primary and secondary urbanization interventions, on the other hand it is part of a neighborhood where there is a lack of green spaces, outdoor meeting places where to spend free time and children can play. Precisely, in a post-pandemic period, this project is a link between the residential space and the in-between space with the city. In this case the courtyard of the building is transformed into a town equipped square with services, currently missing, to be dedicated to games and encounters, while the facades are placed in an open and permeable way with the city with its arches, allowing the visibility of the internal courtyard.

2.2 PNRR: Integrated Urban Plans (PUI): Corviale (Rome), Design Example

The Next Generation EU aims to mitigate the impact of the pandemic making the economy more sustainable and resilient and, in particular, the National Recovery and Resilience Plan (PNRR), which identifies in the implementation of Component 2 (M5C2—social infrastructures, families and communities and the third sector) and the Integrated Plans [14], have given a new impulse to planning the regeneration of some urban areas identified by the Municipality of Rome. The primary objective of the integrated plans is the recovery, renovation and eco-sustainable re-functionalization of existing building structures and public areas to improve the quality of life, the social promotion and entrepreneurial sponsorship. The recovery is not only at the building scale but also at an urban scale including projects related to smart cities, the development and enhancement of social and cultural services. In the case of reuse, the integrated plan provides that the buildings subject to refurbishment or renovation, increase by at least two energy classes and ensure the balance between built-up areas and green areas limiting land consumption, social inclusion through the promotion of local social and health services and new job opportunities, offered by technology and remote work in order to reduce vehicular traffic flows and implement gentle local mobility. The plan is aimed at improving the quality of buildings and making ERP achievements (e.g., PDZ61) owned by ATER more efficient, restoring green areas and public spaces usable. The plan was drawn up with the scientific support of the La Sapienza University and RomaTre and has as its primary objective of the regeneration of the open spaces that characterize the neighborhoods and in particular those margins between city and countryside redesigning two parks (East Park and West Park), in compliance with art. 50 co.3 NTA PRG ("make the settlement system of fabrics more orderly and complete and improve urban quality through a greater endowment of spaces and public services") and renewing some public buildings including administrative, educational, social, cultural, and sports spaces located in the east side. The intervention frameworks provide completing urban regeneration projects already underway by ATER to restore quality in dwelling and to reduce energy consumption and emissions. Particularly interesting are the project of the building called TRANCIA H and small square of arts and crafts, and cavea, the basement (commercial) floor of the Trancia H Building. The Trancia H building is a four-story ERP edifice located on the east side in the PDZ61 of Corviale. The objective of these interventions is a redesign of the open space and in-between buildings with social activities, outdoor meeting places, the reconnection of commercial and residential spaces, and the social inclusiveness of the ateliers/workshops. Artists and associations present in the area as protagonists. The approach to regeneration is always based on sustainability through constant attention to energy efficiency, re-functionalization, and reconnection of spaces. The project for the small square of the arts and crafts and the cavea provides a system of public spaces that are currently not completely used and disconnected from each other. A re-functionalization of services and spaces pass through the removal of architectural barriers for people with reduced mobility, the construction of a connecting ramp between the equipped park and the area below, while targeted demolitions permit the reconnection of the spaces. In this way, the series of open spaces and services also recreate a connection with the space of the covered market and retrain the existing and currently closed shops. The Small sequare is also overlooked by craft workshops, cultural associations and an incubator of ideas represented by the garrison of the laboratory of Town of Corviale of the Department of Architecture Roma Tre. The headroom of Trancia H is a four-story architectural value building with a triple-height glazed central part that connects the small square and the commercial area to the basement of the residential Trancia H building. The regeneration is based on a re-functionalization, a path of inclusion for the construction of an exhibition site for the associations of the small square. The spaces are intended for artistic and exhibition activities in a flexible way. In addition to interventions of energy efficiency and extraordinary maintenance, the inclusion of hydroponic and aquaponic crops is planned with the aim of green systems inserting inside the building in the roof and in the second and third floor.

3 Intervention Strategies for Green and Healthy Housing in the Post-pandemic Scenario

The Sick Building Syndrome (SBS) is one of the underlying issues of the link between building and health, and it often manifests itself in unspecific conditions by a large number of residents in modern or recently renovated buildings, which will significantly affect the decline in productivity. From numerous investigations in buildings where health or comfort problems were reported, it has emerged that the prevailing problem (in almost half of the cases) was inadequate ventilation that causes health problems and discomfort due to the chemical compounds present in the indoor air that cause irritation or stimulation of the sensory system [15]. Concentrations of air pollutants are often between two and five times higher indoors than outdoors. For this reason, the house must be ventilated as much as possible, especially when the outside air is clean: higher natural ventilation rates (in other words, the introduction of healthy air) have been linked to many benefits, including the reduction of so-called symptoms of SBS, such as headache and eye irritation, and help dilute any contaminants that are generated within [16]. The rules of living and the design of condominiums, buildings, neighborhoods, and urban districts are changing after the COVID-19 emergency, and they must be rethought in a biodynamic way with natural ventilation systems, hybrid ventilation and temperature regulation controlled by solar chimneys and wind towers with natural light as the predominant factor which, interacting with artificial light, seeking correct lighting in the rooms, and allowing to save on consumption and to improve the thermo-hygrometric well-being of the filter and indoor spaces. To prevent and reduce the spread of SARS-CoV-2 virus diseases now widely reported by ISS [17] and to increase the energy efficiency of the public and private building stock, explained in mission 2 of the Italian PNRR put in place to relaunch the economy after the health crisis [18], it is necessary to outline intervention strategies, starting from those outlined for improving the energy efficiency of cultural heritage [19], which favor the bioclimatic and ecological functioning of the building based on the parameters of indoor air quality (IAQ), with a view to reducing energy resources, maximizing efficiency and reducing the spread of viral agents, starting from the analysis of the bioclimatic behavior of buildings in their original morphology to optimize their functioning after redevelopment through the reduction of the impact on the micro-climate and atmospheric pollution, the control systems of solar radiation, lighting and natural ventilation, with particular attention to the various choices that can be adopted on transparent closures, and for solar protective devices, such as fixed or mobile screening and/or shading systems, characteristic of the glazed component of the façades.

3.1 Intervention Strategies Aimed at Natural Ventilation and Controlled Mechanical Ventilation

Maximizing natural ventilation, in order to have good indoor air quality and reduce the demand for mechanical ventilation and summer air conditioning, requires proper building design through appropriate window sizing and distribution of rooms according to the required level of natural ventilation and crowding index, ensuring that in a space there are at least two permeable or "active" closures of similar size and geometry open, on opposite sides of the building, to promote continuous air exchange between inside and outside and to trigger the differential pressure necessary to generate air motion; take into account the constructive and functional characteristics of the building envelope for a careful management of ambient air changes, ensuring passive summer cooling through good natural day and night ventilation, making sure that the air with lower temperatures circulates in the room to be cool. Natural ventilation is created thanks to a careful positioning of the horizontal or vertical openings, to the area and type of opening chosen and to the possible presence of shielding, to the calculation of the air tightness of the envelope and the natural ventilation rate, guaranteeing a minimal air exchange to avoid affecting indoor air quality and olfactory comfort as well as creating humidity problems on the walls with consequent formation of mold and condensation; evaluate the climatic context where the building is located to study its exchange capacity between inside and outside through the use of software for dynamic energy simulation and the management and processing of climatic information on the intervention site to evaluate the mode of heat exchange caused by temperature differences and/or heat flows, study the trend of the winds and the thermal gradients that generate the introduction and extraction of air through a confined space, as well as the direction of incidence of the wind on the building in function of which air motions are triggered; create ventilation chimneys that in historic buildings can be built using existing shafts or stairwells or wind towers, whose sides, leeward and upwind, act as collector and wind extractor favoring natural cooling and create bioclimatic atriums in the common intermediate spaces that allow the control of natural ventilation and that can change configuration and function according to the seasons (closed with glazed systems in winter and totally screened and open in summer) and users' needs.

3.2 Intervention Strategies Aimed at Natural Lighting

Rethinking windows and doors by maximizing and spreading daylight inside the building to reduce the demand for artificial lighting and minimize glare by sizing the windows and distributing the rooms according to the level of natural lighting needed, evaluating the exchange capacity between inside and outside, containment of thermal dispersion, capture and use of solar thermal energy, visual and acoustic comfort, air tightness and natural ventilation rate. Careful management of the relationship between energy performance and the building's original appearance must take into account the construction and functional characteristics of the window frame by evaluating the thermal gain of transparent openings, in combination with thermal mass, to absorb solar radiation during the day while accumulating and distributing stored heat late at night; classify in order of incidence on the appearance of the existing building and on the basis of a careful analysis of the amount of sunshine, the parameters that affect the choice of the appropriate solar shading system: the geometry of the building envelope, therefore dimensions, inclination, orientation, location on the plan and section with respect to the internal space, latitude of the site, inclination of the solar rays, orientation of the surfaces to be protected according to the solar axis, the thermo-physical and optical/solar properties of glazed closures such as transparency to solar radiation, thermal resistance of the window and accumulation properties of internal surfaces. Make choices related to the control of natural lighting to ensure the psycho-perceptive and thermo-hygrometric comfort of users based on the activities performed: insert light shelves to screen, direct solar radiation and illuminate the rooms in depth; insert ducts to transport natural lighting indirectly inside the building in cases of internal or underground spaces; insert fixed or mobile artificial shading systems, positioned inside (they allow a more effective mimesis with the building organism) or outside (they have a lower degree of compatibility with the building); and insert solar control glass with shading systems in the double or triple glazing cavity.

4 Post-pandemic Walkable and Proximity Cities

The pandemic period has forcefully brought out new emergencies and needs related to living and domestic space, starting from the flexibility of interior spaces to the need for entry filter spaces for all relevant hygienic precautions. Italy has a dated and inflexible residential building stock [20]; according to the most recent reports available to date, there are 11.9 million buildings intended for residential use in Italy, of these 2.15 million were built before 1919, 1.38 million between the two wars, 1.66 million between 1946 and 1960, just under 2 million in the 1960s and 1970s. In the 1980s, 1.29 million, 80,000 buildings per year were built in the first decade of the 2000s, and from 2011 to 2016 32,000 buildings per year [21].

Reading such data allows us to understand how significant changes cannot be made unless they are part of a rethinking of the urban district vision, integrating variation and modularity of indoor and outdoor spaces of residences. With the pandemic, moreover, all the limitations of living spaces in urban districts today have become apparent. The months of lockdown spent, cohabitating in play, school, work, sports, and domestic activities, often simultaneously for larger families, highlighted the need and necessity for outdoor spaces, privacy in activities, and larger living quarters [22].

The issue of privacy as a fundamental need in a home environment has always been there. The design canons of open space, the sharing of areas of the dwelling when use is not simultaneous and permanent by all members of the household, the use of movable walls, transformable spaces, all refer to needs related to the size or combined use of room-domestic-office type, which had already emerged before the pandemic, now being fully established.

Post-pandemic housing will thus present a profound mutation in shared, neighborhood spaces, in the possibility of implementing grids in a proximity context, ensuring interaction with weaker user groups [23]. Shared spaces may be equipped with mechanical or smart systems to avoid contact with the surfaces themselves in threshold spaces. For living quarters, entry spaces with a filter function for clothing and footwear could be thought of, avoiding possible dispersion of viruses and bacteria. Multifunctional spaces, transformable for different needs at different times of the day, and efficient and innovative spaces for the home office will be part of the new home interior layout strategies, contiguous with the smart transformation-reduction of hall and connective spaces, always present in Italian homes.

4.1 Living in the Time of Pandemics: Design Examples

4.1.1 Living in the Blue Project—Milan Lambrate—Italy

The development (Fig. 1) is spread over 12,404 sq including 8360 sq of owned subsidized housing, 3344 sq of rented subsidized housing, and 700 sq of commercial space on the ground floor. The initiative (Fig. 2), launched in 2014, saw the start of construction in 2016 and completion in 2020 having 104 owned housing units, 46 rental units, 5 commercial spaces, and 2 multifamily housing units (cohousing) with 26 beds.

On the ground floors, two spaces have been made available to the settled community of residents for shared activities and services; the spaces in question provide a multipurpose room for common play and meeting activities among the residents, a "workshop" space for hobby activities, and a common laundry room for the

Figs. 1 and 2 Overall street of the building complex and plan—typical floor plan condominium. The buildings are characterized by their large terraces and buffer spaces, which allow the outdoor space to be experienced as an extension of the individual apartment; the full-height windows present in all rooms further elevate this permeability between inside and outside. The facades of the two buildings depict, like a landmark, the urban-scale principles with which the project layout was developed by emphasizing the value of the central square and characterizing the facades facing toward it with a three-dimensional exposed material such as being blue-colored ceramics, while all the facades that relate to the urban context are characterized by the use of plaster in different color fields that "break up" the large volume of the facades [24].

4.1.2 The Sky of Asnières-Sur-Seine—Asnières-Sur-Seine—France

The project (Fig. 3) is located on an urban axis of strategic importance to the entire city given the upcoming opening of a major train station on the Grand Paris line. The trapezoidal shape of the project area (Fig. 4) defines the design lines of these housing developments. The program consists of 144 affordable housing units and 39 social residences located between the second and eighth floors, including 360 sq of commercial space.

The volumetric composition of the project is divided into three buildings developed mainly along the stretch of the RER C railway line. The project was developed through the study and analysis of multiple environmental parameters: air temperature, humidity, ventilation, lighting, and environmental constraints, and the architectural landmark consists of a series of cutouts, openings and foreshortening that define the three building bodies. The architectural language of the project is based on this notion of "rhythm" (the openings, the materials, the treatment of the upper floors) by promoting the diversity of the urban landscape created between the city and nature [25].

Figs. 3 and 4 North side elevation view and Building plan view

4.1.3 Urbangreen—Paris—France

The project (Fig. 5), with a total area of 6400 sq, is part of an area of residential development in the first urban crown of Paris. The project area (Fig. 6) is located in the area to the south of a new residential complex, and a large undevelopable green zone with which it borders to the south defines the open spaces of the entire compartment. The desire to give visual continuity to the north-south axis defined by the urban composition of the northern subdivision results in the creation of two separate volumes [26].

The latter are defined to ensure continuity with the heights of the adjacent volumes of the new subdivision to the north consisting of 4, 5, or 6 floors respectively to descend through a staircase to the south and harmonize with the context of single-family houses set in the green. The project dialogues with the context and is characterized through the use of matter and light, each front defining its own specificity and narrating the project in different ways. Toward the north, the entrance façade from the main compartment features a white diamond ceramic cladding that reflects light and the Paris sky and defines multiple shades of color. Toward the west, a path open to residents moves through the tree masses facing a facade enriched by projecting balconies. The opposite side, open to the green hill, features a more compact front excavated and stretched to create solar greenhouses. The main access is to the south, which is accessed by a large multifunctional bioclimatic atrium.

Figs. 5 and 6 Axonometric view of the building and plan—typical floor plan

5 Conclusion

In order to improve the performance of buildings, it is necessary to intervene with technical solutions that include a search for environmentally friendly materials and technological innovations for the environment and healthfulness, which are valid to ensure that housing has the necessary requirements for healthy and green housing, starting with an urgent enhancement of natural, hybrid ventilation and natural lighting, which together can play an important role in the control, prevention and spread of infections, as well as in increasing the psycho-perceptive comfort of residents: natural movement of air masses, understood as passive bioclimatic systems and, only where necessary, with the aid of active ones, can be equally and more effective than "mechanical-only" systems for infection control and contribute to the maintenance of good indoor air quality (IAQ) and indoor environmental quality (IEQ).

References

1. Tucci, F. (2018). *Green building and dwelling*. Altralinea Edizioni.
2. Ronchi, E., & Tucci, F. (2020). *Pandemie e alcune sfide green del nostro tempo*. Fondazione per lo Sviluppo Sostenibile.
3. Naglaa, A. M., & Ehab, M. G. (2021). Indoor Air Quality: Rethinking rules of building design strategies in post-pandemic architecture in. *Environmental Research, 193*, 110471.
4. World Health Organization. (2018). *Housing and health guidelines*. WHO.
5. Losasso, M. (2022). Crisi interconnesse e complessità del progetto. *TECHNE, Journal of Technology for Architecture and Environment, 23*, 7–9. SITdA, Firenze University Press.
6. Berman, M. G., Jonides, J., & Kaplan, S. (2008). *The cognitive benefits of interacting with nature*. Research report, University of Michigan (US).
7. Scoppetta, C. (2010). 1. Alcune interpretazioni dello spazio metropolitano contemporaneo, Forme del piano e forma urbana: la "città per progetti". In *Gli "in-between spaces" Elementi caratterizzanti della metropoli contemporanea*. CITTALIA, fondazione ANCI ricerche.
8. Finucci, F. (2021). Come volano i viandanti. In AA VV, a cura di Laboratorio CIRCO, F. Careri, F. Finucci, C. Luchetti, A. Marzo, S. Monaco, S. Olcuire, E. Perini, & M. Rocco (Eds.), *CIRCO. Un immaginario di città ospitale* (Parte IV Issiamo il tendone: laboratorio CIRCO) (pp. 183–192). Bordeaux.
9. Baratta, A. F. L. (2021). Eternamente fuori sede. La residenzialità transitoria degli studenti universitari, da problema a risorsa. In AA VV, a cura di Laboratorio CIRCO, F. Careri, F. Finucci, C. Luchetti, A. Marzo, S. Monaco, S. Olcuire, E. Perini, & M. Rocco (Eds.), *CIRCO. Un immaginario di città ospitale* (Parte II Di equilibristi, domatori e pionieri) (pp. 63–70). Bordeaux.
10. Careri, F. (2021). Autodialogo su CIRCO. Genealogia di uno spazio di relazione con l'alterità. In AA VV, a cura di Laboratorio CIRCO, F. Careri, F. Finucci, C. Luchetti, A. Marzo, S. Monaco, S. Olcuire, E. Perini, & M. Rocco (Eds.), *CIRCO. Un immaginario di città ospitale* (Parte I Una città ospitale) (pp. 21–32). Bordeaux.
11. Comune di Bologna, Iperbole Rete Civica. *Il piano per l'innovazione urbana di Bologna, I luoghi della prossimità*. Available at: http://www.comune.bologna.it/pianoinnovazioneurbana/info2019/luoghi-prossimita/. Accessed 2 July 2022.
12. PINQua, Unità di Missione PNRR del Ministero delle Infrastrutture e delle Mobilità sostenibili, Report, Brisku, C., Capone, G., Ciferri, D., De Leo, V., & Liccardi, S. (2022). *Programma*

Innovativo Nazionale per la Qualità dell'abitare, Progetti e prime evidenze. Available at: https://www.mit.gov.it/nfsmitgov/files/media//notizia/2022-04/Rapporto_Pinqua_web.pdf. Accessed 1 July 2022.
13. PINQua, Mims (Ministero delle infrastrutture e della mobilità sostenibile). (2021). *Selezione di Progetti meritevoli*. Available at: https://www.mit.gov.it/comunicazione/news//pinqua-programma-accelera-breve-280-milioni-di-euro-di-anticipazioni-ai-comuni. Accessed 1 July 2022.
14. Piano Nazionale di Ripresa e Resilienza M5C2 – Investimento 2.2. (2022). *Piani Integrati, ex art. 21 del DL 6 Novembre 2021 n. 152*. Available at: https://www.corviale.com/wp-content/uploads/2022/03/Allegato-piano-integrato-Corviale.pdf. Accessed 3 July 2022.
15. Gasperini, A., & Direzione Generale per la prevenzione sanitaria. (2015). *Sindrome dell'edificio malato – Sick building sydrome*. Available at: https://www.salute.gov.it/portale/temi/p2_6.jsp?id=4404&area=indor&menu=vuoto. Accessed 29 June 2022.
16. Allen, J. G., Cedeno Laurent, J. G., Jones, E., Lahaie Luna, M., Macnaughton, P., Robinson, S., Spengler, J., & Young, A. (2019). *Homes for Health – 36 expert tips to make your home a healthier home*. Available at: https://homes.forhealth.org. Accessed 24 May 2020.
17. ISS Gruppo di Lavoro Ambiente e Qualità dell'Aria Indoor. (2020). *Indicazioni ad interim per la prevenzione e gestione degli ambienti indoor in relazione alla trasmissione dell'infezione da virus SARS-CoV-2*. Rapporto ISS COVID-19 n. 5/2020 Vers. 21 aprile 2020, Istituto Superiore di Sanità, Roma.
18. Ministero della Cultura – ex MiBACT. (2015). *Linee di Indirizzo per il miglioramento dell'efficienza energetica nel patrimonio culturale*, Roma. Available at: https://www.soprintendenzapdve.beniculturali.it/wp-content/uploads/2021/04/Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf. Accessed 17 February 2022.
19. Ministero dello Sviluppo Economico. (2022). *Piano Nazionale di Ripresa e Resilienza*, Roma. Available at: https://www.governo.it/sites/governo.it/files/PNRR.pdf. Accessed 29 June 2022.
20. Losasso, M., & Verde, S. (2020). Strategie progettuali di adattamento urbano ed edilizio in scenari di multirischio ambientale. *AGATHON: International Journal of Architecture, Art & Design, 8*, 64–73. https://doi.org/10.19229/2464-9309/862020
21. CRESME. (2021). *Il recupero e la riqualificazione energetica del patrimonio edilizio: una stima dell'impatto delle misure di incentivazione*. Available at: https://biblus.acca.it/rapporto-cresme-2021-riqualificazione-edilizia/. Accessed 28 June 2022.
22. Orazi, M. (2020). *Gilles Clément and the opportunity after the coronavirus*, Domus. Available at: https://www.domusweb.it/en/architecture/2020/05/29/gilles-clment-coronavirus-is-an-opportunity.html. Accessed 29 June 2022.
23. Lubrano, E. (2020). *Le città del futuro. Ecco i modelli*, Impakter. Available at: https://www.impakter.it/le-citta-del-futuro-ecco-i-modelli/. Accessed 1 July 2022.
24. Gingardi, V. (2017). Processes of urban transformation in Milan: The case of Lambrate. *Archivio di Studi Urbani e Regionali, 48*(119), 51–72. https://doi.org/10.3280/ASUR2017-119004
25. Domus. (2016). I giardini di Gabriel. *Domus for design – Section Architettura*. Available at: https://www.domusweb.it/it/architettura/2016/10/19/i_giardini_di_gabriel_asnie_res_sur_seine_5_1aa.html. Accessed 2 July 2022.
26. Mosco, V. P. (2020). Narrare attraverso l'architettura: Atelier(s) Alfonso Femia. [Complesso residenziale Urban Green, Romainville, Parigi, Francia]. *The Plan, 125*, 18–28. Available at: https://search-ebscohostcom.ezproxy.uniroma1.it/login.aspx?direct=true&db=bvh&AN=820175&lang=it&site=eds-live&scope=site. Accessed 25 June 2022.

Integration of Circular and Green Technologies for the Adaptive Reuse of Public Space

Francesca Giglio, Evelyn Grillo, and Sara Sansotta

1 Introduction

The multiple and increasingly interrelated conditions of emergency (environmental, urban, post-pandemic) are an enabling factor for the circular economy and cultural processes involving the environment, social cohesion, innovation, new technologies, and territorial connections. The challenge of managing and reducing municipal waste is a growing sustainability problem for governments and local authorities, along with the control of all environmental issues. Recycling percentages are increasing, but this is not enough to face the environmental challenges caused by the disposable material culture. Environmentally, around 75% of natural resource consumption occurs in cities, which produce about 50% of global waste and between 60% and 80% of CO_2 emissions [1]. Public spaces within cities are the key element for inclusive, healthy, functional, and productive cities; for this reason, public open spaces can be considered a powerful tool for sustainable development, as they provide environmental, social, economic, and health benefits to the city. Overall, public open spaces reflect the character and identity of a city, giving it meaning in an aesthetic, ecological, and functional sense [2]. Specifically, disused and underused spaces in European cities can become opportunities through urban regeneration, in line with SDG 11 "Sustainable Cities and Communities," SDG 15 "Life on Earth," and SDG 13 "Climate Action," which public open spaces can influence. This condition of underuse not only affects the aesthetic quality of the urban environment but is also a disruptive factor, slowing down development possibilities and affecting people's lifestyles and the evolution of the local economy [3]. For these reasons,

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urban regeneration becomes a relevant prerequisite for achieving the SDGs and means giving new life to portions of land in a state of abandonment or underuse, leading to the birth of new life cycles capable of restoring the right degree of attractiveness.

The evolution of synergetic processes of adaptive reuse for urban regeneration see in a circular design, a dialogic theory of action: a systemic interdisciplinary research framework that experiments with visionary, disruptive, and realistic impact, exploring urban challenges and transformations through bottom-up actions and didactic methods that utilize resources creatively [4]. This theoretical aspect is particularly significant when transferred to the reality of Italy's small urban centers, which represent a capital of humanitarian relations to be regenerated in material and immaterial terms. In the perspective of the circular economy, abandoned and underused cultural heritage can be transformed from a "cost" into an "investment" for society, opening up new perspectives for sustainable local development, enhancing the urban landscape and the well-being of communities, and generating new jobs. Small and lesser-known heritage sites in almost all European cities and regions have great potential to reactivate civic attention [5].

In this context, the article aims to describe the research experience carried out by the authors and transferred into the teaching experience that led to innovative and green design experiments for the adaptive reuse of unused areas, applied to the case study of a historical center in Southern Italy: Cosenza. The challenge was to address and define new innovative and systemic models of Cultural Heritage (CH) intervention through the development of pilot projects that can respond to digital and green transition processes. From a social and open-innovation perspective, adaptive reuse strategies, circular technologies, and unconventional materials trigger regenerative actions for degraded spaces and the community.

2 Adaptive Reuse in Mediterranean Historical Centers

The link between history and the present constitutes an important identity factor; in the Mediterranean, although a great variety of urban models followed one another over time, cities still present themselves in recognizable forms and give frequent signs of new vitality. The historical centers are powerful laboratories to evaluate how Cultural Heritage can become an influential factor in sustainable and economic development for the city and an exciting testing ground for innovative regeneration strategies. The high density and compactness of the built environment determine the specific condition in which people, activities, work, and relationships coexist in a relatively limited area characterized by multifunctional use of space. At the same time, the cultural richness, the architectural context of historical-artistic value, and the interaction between public and private activities that characterize the historical centers are often accompanied by degradation features. These aspects are caused to social and environmental pressure, lack of security and safety, and ineffective management of spaces [6].

The emergency condition of these places is representative of many southern Italian villages, often characterized by complex conditions of seismic safety, environmental management (waste production and resource consumption), climatic conditions, and social dissatisfaction. Places where many (unused) urban spaces are created precisely through collapses, creating urban voids that represent opportunities for experimentation to improve the inhabitants' quality of life [7]. Urban space comprises a complex network of actors and elements that require a holistic approach when considering transforming it into a sustainable model. Through the presence of regenerated aspects of an economic and social nature, the physical structure succeeds in assuming a character of permanence and in contributing to the preservation of the Urban-Mediterranean identity.

Synergetic processes of adaptive reuse of unused spaces through *circular design* strategies represent new models of spatial, environmental, and social rethinking from two perspectives:

1. A *bio-ecological perspective*, oriented toward nature-based solutions to contribute to air quality, landscape, temperature regulation, water conservation, self-production of energy, and soil conservation, thus reducing environmental/territorial fragility;
2. A *humanistic perspective*, oriented toward new uses: repair, recycling, regeneration, and new production activities and services. Furthermore, circular reuse can contribute to reducing cultural fragility [8].

For this reason, adaptive reuse prefigures strategic solutions that can reduce environmental impacts, such as greenhouse gas emissions, by extending the life of the building and preventing the production of construction and demolition waste, and designing low-carbon cities to address climate change as well [9].

3 The Experimentation: Circular and Green Technologies for the Adaptive Reuse of Public Space. The Case Study in the Historical Center of Cosenza

The working method that guides the design experiments focuses on the need to exploit raw materials-second immediately available on-site and greening actions to increase the processes of decarbonization. The aim is to analyze the life-cycle process of materials, activating new natural models that could represent pilot projects of a circular ecosystem.

Actions for research activities consist of the following:

1. An *analytical-theoretical phase* based mainly on two key documents: the White Paper "Design tech for future," [10] a policy document drawn up by a Task Force of designers, companies, and enterprises, which shows how design, combined with technological innovation, can play a central role in overcoming the health and economic crisis—"Sustainable and Circular reuse of spaces & buildings"

[11], a handbook identifying new strategies for the integrated management of urban reuse, according to the principles of the circular economy;

2. A *critical-application phase* that connects the emergency conditions of the context, the environmental and social characteristics with the technological solutions represented by the principles of *circular design* and the integration of *nature-based solutions* (NBS). The integration of these strategies can counteract the negative impacts of urbanization and contribute to a circular economy through the provision of ecosystem services. The adoption of NBS strategies can be seen as a technological innovation focused on nature and the goal of improving natural capital o [12]. According to these assumptions, NBS can simultaneously provide positive environmental, social, and economic impacts and foster territorial resilience. Nature-based solutions integrate concepts such as green infrastructure or ecosystem-based mitigation and adaptation in policy and practice. An advanced extension of the concept of adaptivity and adaptive reuse is transferred and applied to the context through a framework that analyzes three scales of implementation and intervention: green building materials; green building systems, and green building sites, emphasizing the value of vegetated open spaces and water-sensitive urban design [13]. Specifically, green building materials are understood as raw, processed natural materials used to construct the built environment. Green building systems are systems for greening buildings and include components such as green façades, living walls, domestic trees, and even built wetlands integrated into the building. Green building sites can be open spaces directly adjacent to buildings, typically within the same property, or small and medium-scale land that plays a role in the city's blue-green network;
3. An *experimental phase* in which innovative intervention models focus on demonstration projects that can be applied to other similar contexts. The experiments combine cultural and material identities with circular building systems, interpreting reversibility and using alternative materials as a paradigm in the relationship with the context, urban connections, and the revitalization of unused areas. The intervention strategies concern the rethinking of open spaces and meeting places in the historical center of Cosenza, the case study of the experimentation through temporary, modular, off-site, mountable, dismountable structures that can be aggregated to provide adequate services to citizens.

The redevelopment of spaces also involves social innovation activities, involving citizens in urban regeneration activities. The projects have the characteristic of becoming energy autonomous through off-site systems that are independent of system networks and use renewable energy sources. The experimental activity is validated by studying innovative non-conventional materials that characterize the material choice of each building system. The concept of local material is therefore extended to unconventional waste materials also present in large quantities as urban waste. The choice of the case study of the historical center of Cosenza is due to its representativeness, both in terms of historical/cultural heritage representative for the entire city's identity and its isolated and weakened position since the 1950s and still unresolved. The whole area is subject to a process of progressive depopulation and social and economic decline and a gradual loss of those characteristic traditional services that reduce the inhabitants' quality of life. From an environmental and social point of view, the buildings are in a state of abandonment that denounces the need to intervene urgently and quickly in these places, representing an opportunity for innovation and constructive experimentation. Addressing the challenges posed by urbanization and the growth of cities plays a central role in society's transition to a circular economy.

The circular and green technologies of the design experiments[1] (Fig. 1) (TENA-MI′, THE CUBE, PARASITE, and PARA BIOSIS), described in the following paragraphs, propose an experimental and innovative model of intervention through a framework that analyzes three scales of intervention and implementation, adopting the design approach methodology from the current literature [13]: *Green Building Sites, Green Building System,* and *Green Building Materials* which are the focus of the paper.

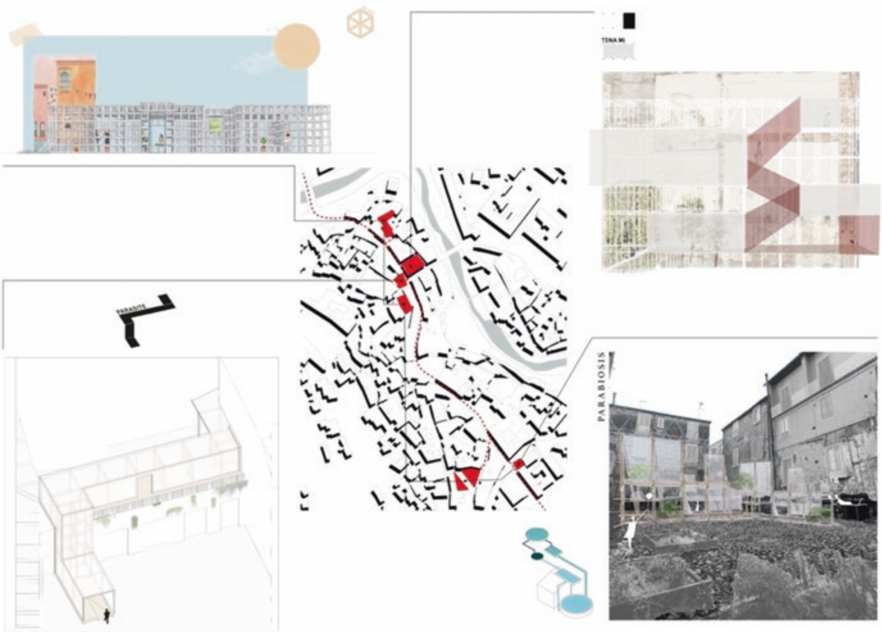

Fig. 1 Project experiments for the historical center of Cosenza

[1] The design experiments result from work carried out within the Course: "Circular Design and Material Innovation" of the Department of Architecture and Territory at the Mediterranea University of Reggio Calabria.

Project Coordinator: Prof. Francesca Giglio with S. Sansotta and E. Grillo.

Project Team: TENA-MI′ – Federico Filice, THE CUBE – Eleonora La Fauci, PARA-SITE – Francesco Del Rosario e PARA BIOSIS – Eliana Catalano.

3.1 Green Building Sites: The Relationship with the Context

Experiments make the relationship with the context the founding element of design. Urban morphology, or the spatial arrangement of buildings, can be a barrier or support between different ways of using public open space. The direction of the wind, the position, and prevalence of the shadows or the duration of the sun intervals depend on the relationship and proportion of the structures built, which also affect the different microclimatic characters of the place. The challenge is to design multidimensional and multifunctional spaces that can represent the quality level of the site. Multi-functionality is assumed as a necessary characteristic for the redevelopment of public areas. It is used with a double meaning: multifunctional use of space as an interrelation between functional, social, and morphological possibilities, in which activities can be integrated and coexist simultaneously; multi-functionality over time of the object as its potential and useful transformation, guaranteeing it new lives.

In this process, the aim is to free experimental projects from the "abuse" of resources through the efficient use of resources instead. This involves using secondary raw materials, waste that is recovered and regenerated into innovative materials and technologies in a green and circular perspective. At the environmental level, the reuse of materials and technologies (adjusted and adapted to the location) can help to significantly reduce negative impacts on the environment and, at the same time, offer users superior performance and improve their life quality by optimizing the use of resources. A common feature of the experiments is the use of simple connections to allow the separation and easy recovery of individual elements. Unlike conventional structures where design is concerned with functional, technical, and physical composition, the design of reversible systems considers decomposition, ease of assembly, and multi-functionality. Thus, the *Green Building Sites* approach considers in an overall profile different constituent element of experimental projects such as the environmental context of reference, spatial functionality and transformability, material quality, constructability, social and cultural aspects, and costs.

TENA-MI′ (Fig. 2) is attached to a historical aristocratic palace in Cosenza that is now the location of a cultural association. The project relates to the more populated front, opening up the possibility of creating visual and physical relationships between passers-by and users of the space. The footprint, both in plan and elevation, follows the scanning module of the palace, becoming a contemporary re-proposition of what it was. The project enhances the elevation it clings to, framing it within the metal grid, with which it is made using iron tubes, very common in the historical center, used as supporting structures for buildings. The need to optimize and benefit from natural light, even if never direct, influences the layout of the rooms and related activities. The higher floors are conceived as places to observe the surrounding space from different perspectives and thus come into contact with the town of Cosenza through different positions and visual perceptions.

The experimental project *PARASITE* (Fig. 3) is inserted into a pre-existing space structured on two levels, one for the street level and the other on which the

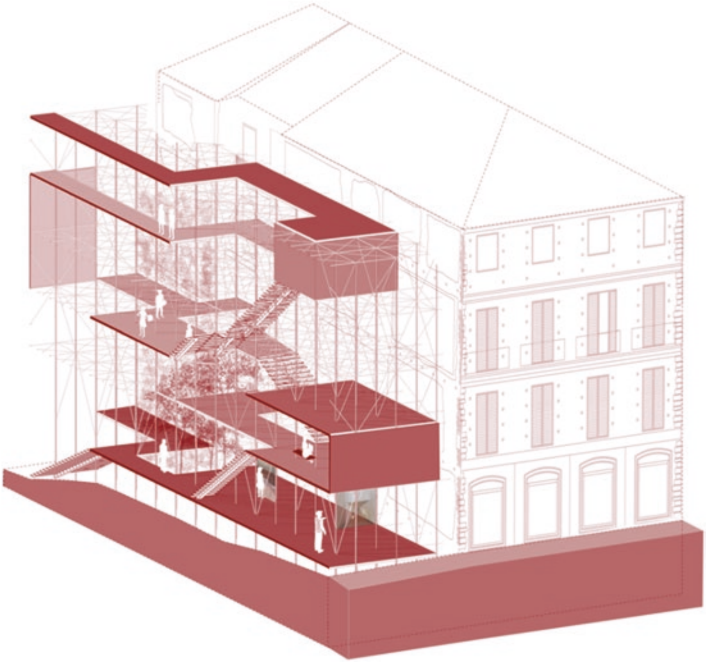

Fig. 2 TENA-MI′

intervention rests almost entirely. The scanning given by the flooring is the module on which the entire project is based. The experimentation takes up the morphological conformation of the square, translating as a real parasite that addresses the issue of accessibility, which is particularly critical in the historical center.

If in the case of *TENA-MI′* and *PARASITE*, the experiments take the form of urban scenes in which to cling to the context, in the case of *THE CUBE* (Fig. 4), correspondence is maintained with the main entrances and framing of the existing openings. The site is an empty urban space strongly characterized by the citizens' own denunciation manifested through the representations on the ruined façades of the surrounding building (Fig. 5). The project has a twofold objective: to return a shared space to those who live in the square daily and to give new life to a neighborhood in such a state of abandonment. The constituent elements of the area's current state, such as the staircase connecting the metal platform along the inhabited side and the stone steps, are accompanied by raised paving that will facilitate access. The empty module allows the architecture not to create a visual obstacle but to maintain the surrounding view at every point of the project.

The design approach methodology changes considerably in the case of *PARA BIOSIS* (Fig. 6), where the relationship with the context is systemic. The context is modeled and becomes a palimpsest, lending what is its fulcrum: the abandoned buildings of the historical center in a univocal system. The buildings, now abandoned and left to live a life of their own, become the first level of the project, the

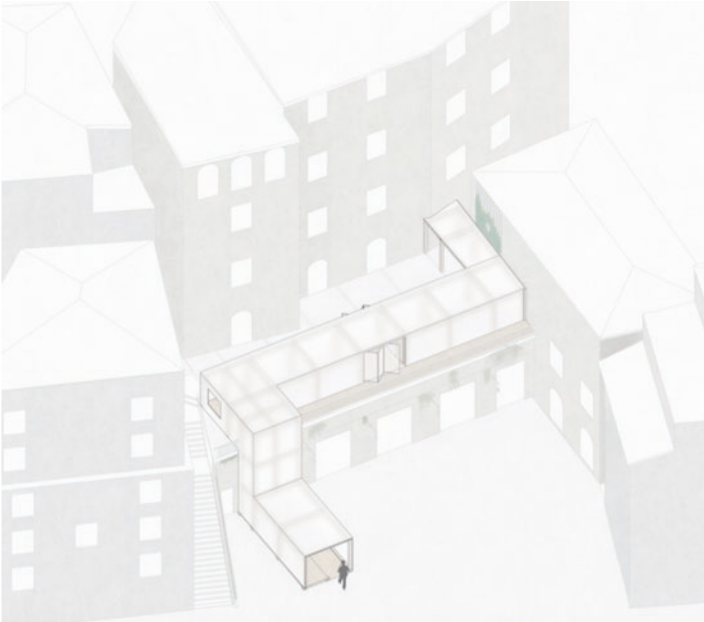

Fig. 3 PARASITE

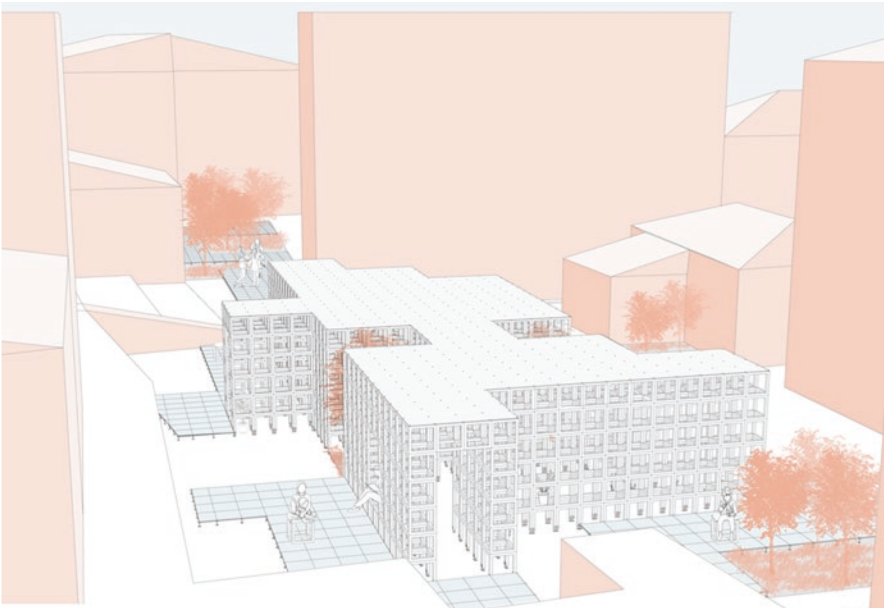

Fig. 4 THE CUBE

Fig. 5 Critical analysis of the state of the art for THE CUBE experimentation

Water Towers, which become real collection tanks that utilize the entire roof; their function is not limited only to the collection of water, but they themselves become a device where workshops can be held, creating a direct relationship with the community. The buildings that connect the four squares considered are the circulatory system that unites the two independent systems, water, and context, causing water to flow along these arteries leading to level III of the project.

3.2 Green Building System: Experimentation with Circular Technologies

Using locally available resources to promote sustainability goals, outdoor comfort, healthy living environments, and well-being in green cities aims to define a virtuous circular process and protection from pollution. This could depend on the approach based on the effects of specific vegetative configurations, such as linear and vertical configurations. This approach is foundational for *PARASITE* experimentation (Fig. 7). The adoption of *Hedera Helix* aims to protect and conserve ecosystems by preserving biodiversity and, at the same time, act as a gas absorber by reducing CO_2 concentrations and improving air quality by mitigating the effects of high temperatures.

The *TENA-MI′* project adopts a moving and de-flooring solution throughout the entire site to create a small natural drainage system below the project ground level, where the design provides for low, spontaneous vegetation. The greening actions are inserted in the ground and the vertical walls, through the internal garden that forms

Fig. 6 PARA BIOSIS

between the structure and the ancient courtyard of the palace, adopting shrub/essential vegetation such as lavender, thyme, rosemary, and some trees such as Ficus Benjamina, useful to re-establish the natural ecosystems by transporting them from the river banks to the historical center. Other tree systems are Ivy, Ficus Pumila, and Plumbago, the latter in particular for its officinal characteristics linked to its ability to purify environments of lead.

In the *PARA BIOSIS* project (Fig. 8), the relationship between the ecosystem and the water cycle is the key element of the ecosystem. On its largest scale, the water is collected through the first level of the project, the Water Towers, or abandoned buildings converted for this purpose. It then flows through connections that lead it back to Level II, the terraces of the buildings in the historical center, where further water is collected. All the rainwater collected flows into a system of reuse and

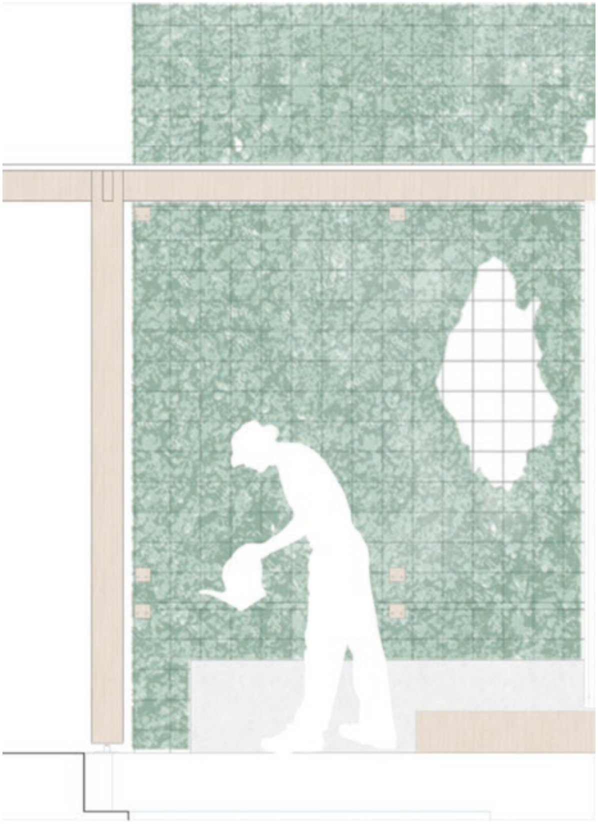

Fig. 7 Vertical Vegetation Solution_PARASITE

redistribution that ends in level III, the device in the square. Through these three levels of rainwater collection, there is a greater collection than the normal runoff, which leads to no more accumulation resulting in flooding of the historical center.

3.3 Green Building Materials: The Solutions Adopted

The availability of local resources and the possibility to apply up-cycling techniques extends and innovates the concept of local material by looking at recovered, reused, unconventional materials for the construction industry.

The *TENA-MI′* project (Fig. 9) originates with the idea of maintaining the circularity of the processes by which materials and components are used. Starting with the structure, all the technological solutions adopted are reversible. The system in iron tubes is designed to be disassembled and remodeled according to the needs of the place where it is to be placed. The stairs are industrially produced from the

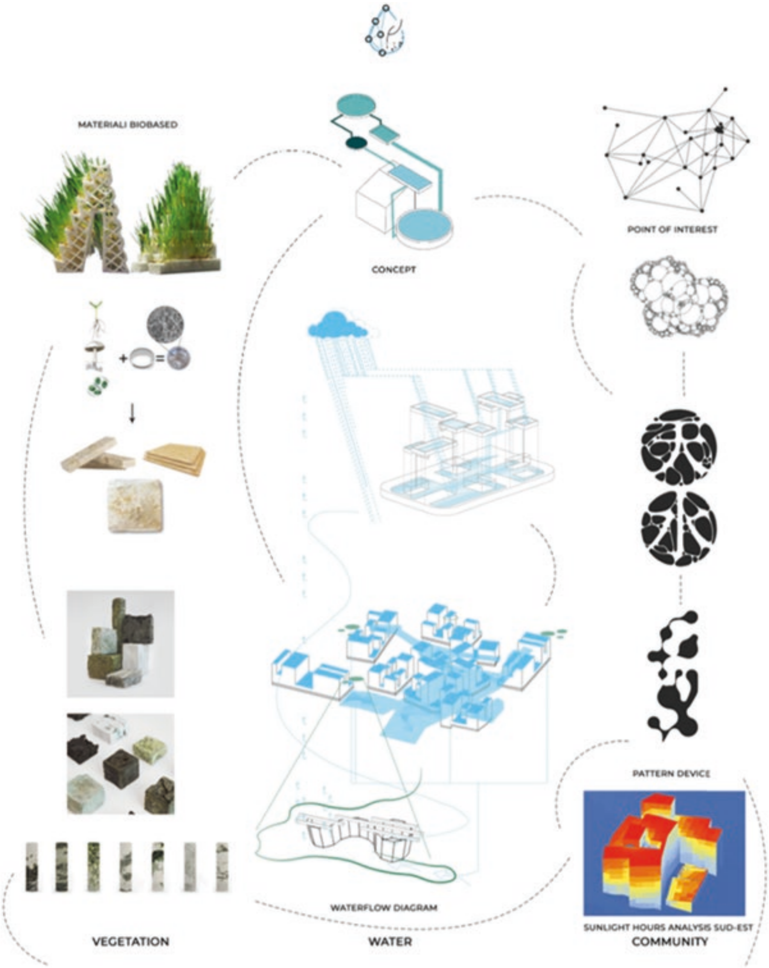

Fig. 8 Life Cycle of Water_PARA BIOSIS

production chain of construction site scaffolding. To define the different functions of the stairs from the rooms, it is decided to use woven wool recovered from knitting scraps and discarded clothing. The colored wool threads are woven (to increase their strength) and act as a filter to shade the rooms while maintaining a humid microclimate due to their ability to retain dew during the night. Different solutions are adopted for the design of the cladding panels. Panels of rice paper covered with 1 cm micro-perforated Plexiglas sheets are used for the open spaces. Rice paper is a material derived from the waste of the rice production sector in Calabria. Another type of panel is formed by hot pressing ffp2 masks, which are collected and screened, then shredded and pressed, resulting in a panel with colors similar to colored granite.

THE CUBE system (Fig. 10) consists of a metal frame fixed to the base using adjusting devices. Square wooden panels are used for the cladding and completely

Fig. 9 TENA-MI′

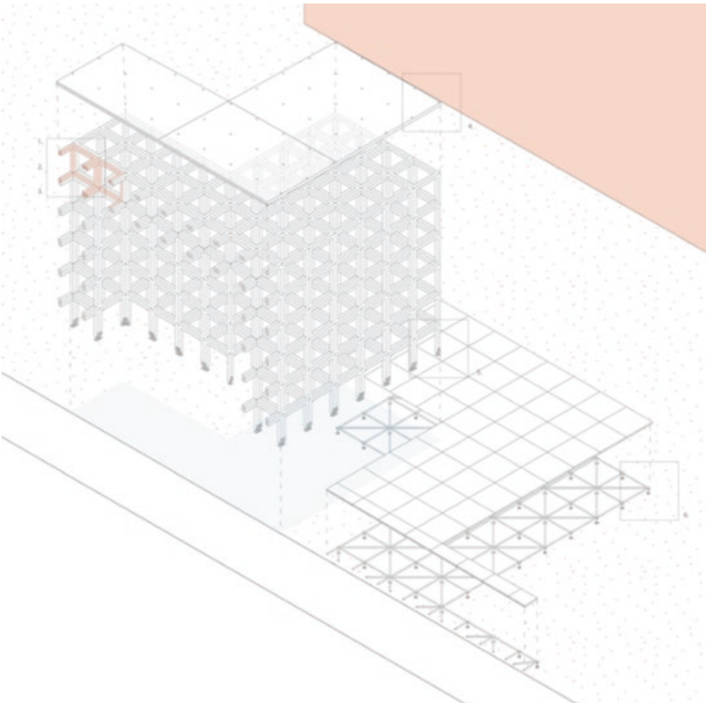

Fig. 10 THE CUBE

hide the load-bearing metal system. In the center of the area, the conceived space is a box-like wooden envelope connected to the metal system by metal brackets. Each cubic module is realized by a Japanese "sashimono" triple interlocking system, allowing quick and easy assembly without additional metal elements. The box structure is obtained by tessellating the units with two anchors on each side. For the roofing, glass sheets divided into 2 × 2 m modules bolted at the nodes of the cubes were used. The modules include some removable elements that serve as 40 × 40 cm seats.

The availability of local resources and the possibility to apply up-cycling techniques, extends and innovates the concept of local material by looking at recovered, reused, unconventional materials for the construction industry.

4 Conclusion

Reversibility and alternative/circular materials are the paradigms of a just transition with a regenerative and adaptive reuse approach for unused or underused spaces. These activities aim to help the city reactivate social and cultural innovation processes, together with environmental regenerative processes through systemic experiments of circular adaptive reuse. The study of projects for the recovery and reuse of urban spaces concerns a number of themes and places that offer a transversal reading of the processes of modernization and preservation of the Mediterranean urban identity. The comparative reading of the experiences analyzed and the interpretation of the scales of implementation of the interventions proposes new dynamic models of intervention for temporary, circular, reversible reuse, together with the cultural and creative rethinking of relational spaces with a focus on safeguarding the classical imprint of Mediterranean cities. A common feature of the experiments concerns the use of plant species typical of the Mediterranean area, for example, *Ficus benjamina* as a tree species and lavender, thyme, and rosemary as a shrub/aromatic species to emphasize the identity characteristics of the place. The revitalization of historical centers inevitably originates from a bottom-up approach that becomes an integral part of the regenerative process, feeding itself and finding new possible forms of second life. The temporary nature of the demonstration projects expresses the experimentation and innovation level using available resources and integrated circular and green technologies through a dynamic and incremental approach to circular design strategies. The transfer of research activities on adaptive urban reuse strategies through circular and green building technologies to educational activities contributes to the necessary and fundamental dissemination of knowledge at all levels.

The contributions of the individual experiments relate to the main fields of interdisciplinary socio-environmental science, intended as pilot projects for urban ecosystem services provided by multifunctional urban green spaces, evaluating the benefits of nature-based solutions for human health and well-being. Experiments are replicable models for other similar conditions for the cultural, material, and immaterial heritage of the villages. New intervention models, even disruptive to the canonical models of reuse and rethinking of spaces, respond with innovative and experimental technological solutions to the time of transition, with synergic, inclusive processes capable of activating new forms of social, cultural, and technological innovation.

References

1. Ibáñez, C. S. (2019). Circular design in everyday urbanism: Towards regenerative and restorative dynamic spaces in cities. *Visions for Sustainability, 11*, 9–16.
2. Vukmirovic, M., Gavrilovic, S., & Stojanovic, D. (2019). The improvement of the comfort of public spaces as a local initiative in coping with climate change. *Sustainability, 11*, 3–5.
3. Iodice, S., De Toro, P., & Bosone, M. (2020). Circular economy and adaptive reuse of historical buildings: An analysis of the dynamics between real estate and accommodation facilities in the city of Naples (Italy). *Aestimum*, (Special Issue), 103–124.
4. Daldanise, G., Gravagnuolo, A., Oppido, S., Ragozino, S., Cerreta, M., & Esposito De Vita, G. (2019). Economie circolari per il patrimonio culturale: processi sinergici di riuso adattivo per la rigenerazione urbana. In *Atti della: XXI Conferenza Nazionale SIU | CONFINI, MOVIMENTI, LUOGHI. Politiche e progetti per città e territori in transizione*, Firenze, pp. 1348–1361.
5. Gravagnuolo, A., Micheletti, S., & Bosone, M. (2021). A participatory approach for "circular" adaptive reuse of cultural heritage. Building a heritage community in Salerno, Italy. *Sustainability, 13*, 1–2.
6. Boeri, A., Gaspari, J., Gianfrate, V., Longo, D., & Pussetti, C. (2016). Il riuso adattivo dei centri storici. Bologna e Lisbona: soluzioni per la rigenerazione urbana. *Techne. Journal of Technology for Architecture and Environment, 12*, 230–237.
7. Giglio, F., Sansotta, S., & Grillo, E. (2022). Reversible building technologies and unconventional materials for the circular and creative reuse of small centers. In *5th international symposium New Metropolitan Perspective 2022*, Reggio Calabria, 25–27 May 2022. https://doi.org/10.1007/978-3-031-06825-6_265
8. Girard, L. F. (2020). The circular economy in transforming a died heritage site into a living ecosystem, to be managed as a complex adaptive organism. *Aestimum, 77*, 145–180.
9. Yung, E. H., & Chan, E. H. (2012). Implementation challenges to the adaptive reuse of heritage buildings: Towards the goals of sustainable, low carbon cities. *Habitat International, 36*(3), 352–361.
10. White Paper "DesignTech for Future". (2020). *Design e tecnologia per progettare il mondo dopo il COVID -19*. DesignTech.
11. Partnership on Circular Economy and Sustainable Land Use. (2019). *Sustainable and circular re-use of spaces and buildings – Handbook*. Available online: https://ec.europa.eu/futurium/en/circular-economy/handbook-sustainable-and-circular-re-use-spaces-and-buildings.html (accessed on 6 june 2022)
12. Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy, 93*, 101–111.
13. Pearlmutter, D., Theochari, D., Nehls, T., Pinho, P., Piro, P., Korolova, A., et al. (2020). Enhancing the circular economy with nature-based solutions in the built urban environment: Green building materials, systems and sites. *Blue-Green Systems, 2*(1), 46–72.

Transitional Spaces as a Domain for Public–Private Engagement in Urban Regeneration

Luca Caneparo, Mauro Berta, and Alessandro Di Renzo

1 Introduction

This short contribution draws on work on an ongoing research project involving the Department of Architecture and Design (DAD) of Politecnico di Torino, in collaboration with the Municipality of Aosta, the Regional Residential Buildings Agency (ARER) of Valle D'Aosta and some project workers operating in the Valle D'Aosta region; already, in this first phase, on top of specific interest for the case study, it has enabled the advancement of some considerations of a more general type on a question which is met with increasing urgency in the contemporary city.

At the heart of this reflection, there is a possible link between the various buildings refurbishments (architectural, energy) of the existing residential heritage—particularly the public one—which at the moment can count on a particularly favorable combination of resources and implementation channels, and the parallel route of urban regeneration processes at the neighborhood scale, which seem to be capable of associating the physical refurbishment of spaces and built objects to the building or rebuilding of social practices in which the local community may recognize itself and feel adequately represented [1].

The architectural scale and the urban scale – although both supported by wide-ranging debates, vast literature, and rich records of studies – still too often tend to proceed on parallel lines and to communicate with difficulty. The causes of that can be understood in several ways: firstly, the funding lines and the promoters themselves often have different tendencies and approaches. Secondly, when considering the architectural and urban transformations together, a matter of threshold emerges: the theme of the boundaries (between public and private, but also between inside

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and outside, between the individual and the community) eludes the rigid schemes of the ordinary regeneration levers and requires the use of adequate tools – culturally even more than procedurally – to manage these transition spaces.

In a combination such as the current one, in which the refurbishment of the building's heritage is fully monopolized, even in strictly activating terms, by merely technical questions linked to the optimization and quantification of the performance of the building envelope, that we wish to turn our attention toward is, in other words, the necessity to steer these partial actions toward strategies of urban value, for at least two different reasons. First because, as has been long argued, urban regeneration remains, on the physical level, an operation of re-mixing, re-valuing, and "re-composition" of the existing city [2], which feeds on actions carried out primarily on the built heritage; second because some recent experiences, such as the EPOurban Project—financed by the Central Europe European Programme, which saw the participation among others of the municipality of Bolzano—have shown how the combined activations of tactical actions of energy retrofit and of strategic operations of urban refurbishment not only allow easier building of consensus and cohesion around the operations, but at the same time facilitate more efficient forms of alliance and cooperation between public and private subjects [3].

2 The *Cogne* Neighborhood

2.1 A Test Case for an idea of the development of Urban Mountain Areas

The case examined is the *Cogne Neighborhood* in Aosta, born as a workers' residential settlement to the west of the city center from 1918 onward, on the initiative of the steel company Cogne Acciai Speciali. It is a neighborhood that has seen, in the last decade especially, a progressive impoverishment of its qualitative standards, shown either in a generalized physical decay of public spaces and of some of the oldest buildings, or in the widespread appearance of a broad series of social difficulties, which have inevitably worked to reinforce and exacerbate some of the existing physical problems (Fig. 1).

With regard to this situation, already the subject of some recent interventions focused on the refurbishment of some heritage buildings, an important opportunity for intervention arose with the national Call for Proposals relating to the National Innovative Housing Quality Programme (PINQuA), introduced by the Finance Law 2020 and activated by a subsequent Interministerial Decree of the same year, the aims of which include "refurbishing and improving the heritage designated as social housing, regenerating the socioeconomic fabric, improving accessibility, the safety of places and the re-use of public buildings and spaces, as well as improving social cohesion and the quality of life of citizens, through a lens of sustainability and densification" (Interministerial Decree 395/2020, Preface). With this provision, later

Fig. 1 The new *Cogne Neighborhood* in 1930. (Cogne Archive - Regione Autonoma Valle d'Aosta)

merged with the more general stream of instruments activating the N.R.R.P., a budget line was activated totaling 853.81 million euros for 271 national projects for the refurbishment of the public housing heritage, of which the project presented here—edited in the form of a Technical-Economic Feasibility Project by the Aosta firm Atelier Projet, with the DAD as technical-scientific consultants—obtained a contribution of around 15 million Euros, currently based on the successive phases of design.

Notwithstanding its location in the city of Aosta, which possesses a fundamental link with the Alpine environment, the *Cogne Neighborhood* presents several characteristics that make it similar in some aspects to numerous other districts of the same type and era, and these characteristics are also present in environments that are not strictly Alpine. The regular urban texture, the types of multi-story in-line buildings often with distribution via a communal balcony, and the large public or semi-public open spaces are characteristics that may be widely met at the general level of the architecture of social housing in both the first and the second half of the twentieth century. From other points of view, besides, the settlement presents some original characteristics, linked either to the typology of the oldest buildings (*Stura-Filippini* and *Giacchetti* blocks) or, from a more urban point of view, to the extreme closeness to the city center and in particular to the area of the new headquarters of the University of Valle d'Aosta, which is investing resources very close to this area with a view to future expansion (Fig. 2).

One of the most interesting elements of this case study is, above all, what is today defined as "metromountain"– or metropolitan mountain – condition [4, 5]; this notion refers to the hybrid nature of a settlement fully inserted into the Alpine context which both participates in the physical and social dynamics of the mountain

Fig. 2 Aerial photograph of the *Cogne Neighborhood* of Aosta (2020)

milieu and thus is gifted with a certain sort of autonomy, and which is at the same time an eminently urban place, either for its urban characteristics or because of the presence of something that takes a supra-local value, such as the university. This particular condition allows us to question some firm assumptions, such as the worn-out urban/mountain division and to propose unhindered visions for the future of a settlement that is trying to find its own identity today.

2.2 A Strategy for Regeneration

The layout of the neighborhood, although extensively transformed over the course of time, is still clearly imposed on the grid defined by the initial project; successive phases of housing construction and transformation are however visible in the variations of the typological and morphological characteristics of the different zones. The first nucleus, on the eastern side, is built on the typological models of the open-courtyard block (Stura-Filippini and Giacchetti blocks) and the terraced house (Managers' Villas), which define a still essentially urban settlement model. The expansions on either side of the Second World War (Fresia Basse and Gazzera) in effect abandon the style of the courtyard block to take inspiration from the typology of in-line houses built in parallel rows oriented in a north-south direction; the fabric here gives place to the built and the public space loses the hierarchical connotations between the "inside" and the "outside" of the blocks, to become a substantially neutral substratum on which buildings rest. The construction of the last, western section (Fresia Alte and Nuova Stura) finally finishes the settlement in the same incremental style, leaving a substantially undefined open space on the street today called the Mont Fallère street.

The result today is a neighborhood still effectively legible on its original layout, which has however undergone notable transformations, including the building of new connecting units between the north-south rows after the Second World War; the construction in the 1980s of a notably high residential tower block now due for demolition (renamed “skyscrapers” in the local vulgate) to the north of the Stura-Filippini block; some currently unusable underground parking spaces; several three- and four-story in-line buildings; and the completion of a few courtyard blocks. The substantially incremental and un-coordinated nature of these transformations, not only of the buildings component, but also of the open space, has resulted in the progressive loss of the architectural quality of the public spaces, which today have ended up fragmented, difficult to use, and in general very much run-down.

This progressive decay that has involved the neighborhood in the last decade is the result of a long-term process which has multiple social, procedural, and economic causes, and which currently affects a large community of inhabitants of that part of the city, who find themselves living through this increasing decay in the twin roles of citizens, as regard the impoverishment of public space, and of residents, as regard the obsolescence of the buildings.

The choice shared by the city of Aosta and the ARER has therefore led to the definition of a program based on two types of actions: first, an overall strategy for the whole neighborhood, aiming to reconnect the fragmented tissue of public space and to re-balance the use of open space in favor of pedestrians and cyclists; second a series of individual energy and typological refurbishment operations of some of the existing, no longer adequate buildings.

2.3 Neighborhood and City-Level Strategies

The unifying act of the project is the transformation of the central main street, Colonnello Alessi street. At the moment, the axis is not so perceived; the subtraction of significance and functions is the result of the cumulative factors of the settlement considered above, and of administrative and managerial incoherence that has produced very visible results. For example, in the place which could potentially be the hub of the neighborhood, Soldats de la Neige square, it has produced architectural barriers, enclosures, and precincts, even though they are used for public or community purposes such as schools.

The project affirms the value of continuity firstly of public space; connecting and distributive axes for functions, first occasional, later made continuous and communicating, such as schools, commerce, associations, and the headquarters of activities serving the community. The creation of a continuous axis for cyclists and pedestrians allows them to be placed in a relationship and also to perceive those functions not as separate and distinct but interrelated, an identifying network for the residents of an area, which, although next to the city center, is often perceived as separate and isolated. Moreover, the neighborhood is frequently perceived by the residents, but also by the rest of the citizens, as an entity split up into enclaves, each one gathered around characterizing ethnic, community, or social elements, but also perceived as isolating and a problem for the community and the city (Fig. 3).

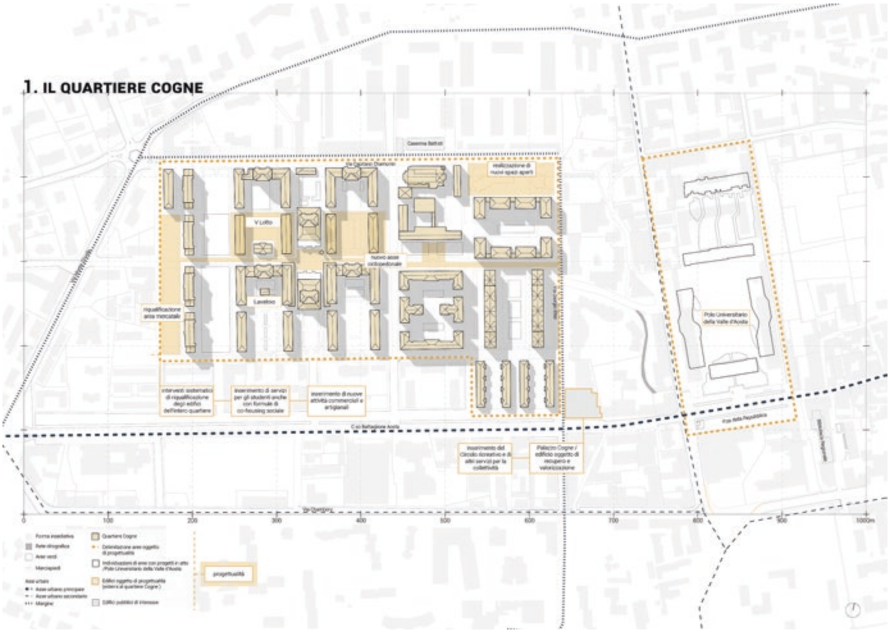

Fig. 3 Map of the interventions of the *Cogne Neighborhood*

The project affirms the value and the unifying function of this axis for the very life of the neighborhood, taking back ownership of public space, and giving cyclists and pedestrians priority over other traffic. These operations as a whole define a cyclist and pedestrian artery that will cross the neighborhood from east to west and allow it to be effectively connected with the city center and the new University site.

The axis will be largely freed of parking spaces, thanks partly to the availability of new parking places in the covered spaces in Liconi street, made available again by the project, through its updating to match the current regulations.

The unity of the connective public space is later shown through the morphology and material characteristics: absence of pavements, stone paving, level collection, and distribution of rainwater.

2.4 Individual Strategies

The gardens in Vuillerminaz street are today an important place of meeting and recreation for the whole neighborhood. Colonnello Alessi street, as a vehicular axis, in fact currently divides what could potentially be a single area into two spatially and functionally distinct zones: to the South a garden furnished with play equipment, games, and infrastructures for school-age and preschool children; to the North mainly designated as vegetation. The project intends to build a unitary dimension, updating the recreational functions, through more modern and attractive sports equipment, diversifying the functions, including on a seasonal basis, to better designate the gardens for example as a base for "summer centers." Meanwhile, the redesign of currently broadly undifferentiated green spaces is exploited to create areas for rest and meeting, shown and characterized through the planting of new entities with the function of shelter and mitigation of the winter weather, through windbreaks, and the summer weather, through extra-shady zones.

The marketplace area, on the western border of the neighborhood, is currently given over to parking on asphalted surfaces, and 1 day per week it is used for a local market.

This area resists a compromise between the two functions, which has for years prevented the definition of an identity of its own either in terms of buildings or of public space. This outcome, today, reoccurs in many urban situations: an empty space that is listed halfway between a road distribution axis and a sort of linear piazza, of which, however, it possesses only the negative characteristics, in subtraction, but not the positive morphological properties and the necessary functional conditions to give it an identity.

The project starts with the definition of new paving, which aims to define two new clearly interpretable spatial modules: the divisions of the parking lots, and the partitions of the market stalls. In order to avoid interference between the design of the paving and the signage systems of the two functions, the project establishes three distinct textures with the help of easily recognizable materials: a first texture of order is constructed in stone stripes, to mark the sequence of the parking lots and the walking routes; a second texture is signaled in the ground through brass strips, inserted into the paving elements, to delimit the market stalls; and a third through brick paving, laid in such a way as to show the different usage designations of the boundary.

The demolition of the so-called "skyscrapers" at the corner of Elter street with Capitano Chamonin street finally frees up an area that the Administration intends to designate as public space, dedicated to the heritage of the workers' neighborhood and the work of the Cogne steelworks.

The project foresees several functions, shown through different typologies of surface organization: vegetation in tubs, to host shrubs and trees of low to medium height; grassed zones with reduced contributions of land for vegetation; paved areas. It is also planned to have a play area with play equipment for children, visually open to the surrounding seats. The surrounding areas offer a connected range of places for rest and socializing.

2.5 *Refurbishment of the Fresia Buildings*

The Fresia Buildings constitute the expansion toward the west during the period of post-war reconstruction, the in-line houses on the model of the external balcony access "case di ringhiera" of the workers' cities (Fresia Basse, 1942–46), in parallel lines of three stories with a north-south orientation.

The design for building refurbishment and town regeneration in the Fresia Buildings offers one interpretation of seamless transition between private, semi-private, semi-public, and public spaces. Continuous transition is shown in the urban section, where a sequence of designations may be seen:

- Private, balconies, and sunrooms
- Semi-private, staircases, and external corridors
- Semi-public, frontages, communal gardens, and community gardens
- Public, roads, pavements, hedges, green verges, green spaces.

The making of each space is defined through needs, which renders it unique and personal, a sign of functional and material diversification. The urban section illustrates the connections and the diversity of transition spaces, functional to the clarity of the designations and the management modes, followed through the search for spatial continuity.

3 Analysis of Transitional Spaces

Typological classification assists in the analysis of transitional spaces. The aim is the study of these spaces, which lies between the private dimension (dwelling, office or retail)—and the public one (street, neighborhood, city).

Categorizing spaces according to types has several aims, for example, research, regulations-norms, and design. Commonly, each purpose names its own types. On the other way, the structures and elements in their morphological- and temporal-evolution have been studied through the analysis of types.

A brief review of urban public space research through the lens of type suggests that researchers often focus on a particular type of space and that the types of interest to researchers and the perspective taken toward them have changed over time [6].

A more exhaustive and analytical study of transitional spaces is purposeful not just to research, but also to the aims of designers and of public bodies in charge of spatial planning and administration.

The value of categorizations lies in their classes, which should allow a clear reading of spaces. Preferably, categorizations should be mutually exclusive and simplify identification and the placing of space instances in the appropriate categories.

The comparative analysis of 11 cities conducted by Carmona et al. [7] showed that the classifications used for the management and long-term planning of public space had some common features but were not fully compatible. The common trait of the classifications studied by Carmona is based on the definitions of sizes and functions, not surprisingly, considering the main administrative function of these definitions.

Nearly all cities use public space typologies as part of their approach to public open space management, most often classifying spaces by size and function [7], by the following:

- Location according to their position in the city (i.e., Wellington's city open spaces, suburban open spaces, inner green belt, the bays, outer green belt)
- Environmental criteria and natural value/protection
- Potential uses as well as existing uses
- Ownership
- Relative protection from development
- Heritage value
- Management responsibility
- Professional responsibility (i.e., gardeners or foresters)
- Required maintenance approaches and tasks
- Special equipment requirements

Morphologically, transition spaces are made up of all those morphological varieties between street and home. The very nature of transition means that the description cannot refer only to the individual dwelling or group of dwellings, nor to the street or the surrounding area; it must rather include large-scale movements between the architectural and planning level. The study of transition spaces, therefore, poses an eminently interdisciplinary and multiscalar challenge. At the same time, the methods for their design and creation contribute to defining added value at both private and public levels; the effects are important both for the formal aspects and for the practices of daily life (Fig. 4).

4 Conclusion

The current project in the *Cogne Neighborhood* tackles the theme of public space from the interaction between a wide variety of spatial configurations, from those of social housing (block housing, terraced housing, and in-line housing) to those that are truly public. The ideal-typical figures of public and social life (the street, the

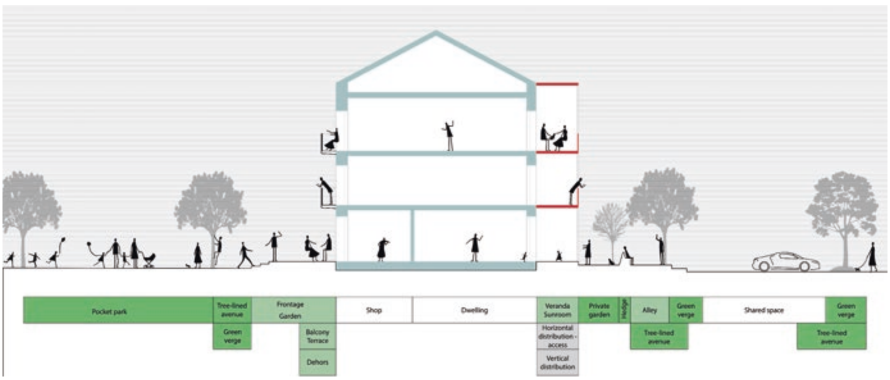

Fig. 4 Cross section of the refurbishment for the Fresia Buildings: continuity between private, semi-private or semi-public, and public space

piazza, the garden/ urban park) are in reality connected in a vast range of instances which urban design began to develop from the twentieth century onward [8].

The project takes as its objective an open and plural urban form, capable of linking a variety of conflicting and competing needs in Aosta's unique urban and social situation. The open nature of these spaces is translated into spaces for social connection and relationships, the intervention strategies considered above, at the neighborhood and city level and at the individual level.

What we briefly described is a very ambitious project, still under definition. Before the physical result of the transformation can be observed, it is undoubtedly too early to draw firm conclusions. At the same time, however, it is interesting to note how the strategy described above has built a discussion table which has been extremely effective in bringing the public administration and the various actors involved in the transformation into dialogue. The design of the Masterplan of the Cogne Neighborhood, understood as a tool which may be falsified, has allowed the raising of needs and the setting of objectives that otherwise would probably have remained unexpressed.

References

1. Mazzette, A. (2013). *Pratiche sociali di città pubblica*. Laterza.
2. Spagnolo, R. (2012). La rigenerazione urbana come problema di ri-composizione architettonica. *Territorio, 63*, 67–69. Franco Angeli. https://doi.org/10.3280/TR2012-063015
3. Verones, S., Rinaldi, A., & Rebecchi, S. (2014). *Retrofit e rigenerazione urbana. Il progetto EPOurban*. Edicom.
4. De Rossi, A., Barca, F., Barbera, F., & Carrosio, G. (2021). *Metromontagna un progetto per riabitare l'Italia*. Donzelli.
5. Corrado, F. (2021). *Urbano montano verso nuove configurazioni e progetti di territorio*. Franco Angeli.
6. Franck, K. A., & Huang, T. S. (2020). Types: Descriptive and analytic tools in public space research. In V. Mehta & D. Palazzo (Eds.), *Companion to public space* (pp. 209–220). Routledge.
7. Carmona, M., de Magalhães, C., & Hammond, L. (2008). *Public space: The management dimension*. Routledge.
8. Viganò, P. (1999). *La città elementare*. Skira.

Marine Energy Sources for Decarbonization of Mediterranean Regions Through Maritime Spatial Planning

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1 Introduction

The Mediterranean is among the areas most affected by climate change worldwide, such as in terms of temperature increase, drought and extreme weather events; therefore, consistent mitigation and adaptation actions have to be hypothesized and implemented in the next future [1]. Due to the risks of global warming, urgent actions are needed to transform modern energy systems into low-carbon alternatives [2] through the development of distributed and integrated energy systems with a high penetration of renewable sources [3], including innovative solutions.

The Interreg Med MAESTRALE [4] and BLUE DEAL [5] projects investigated the potential of Blue Energy (BE) as renewable energy from marine sources exploitable for supplying Mediterranean islands and coastal areas. In order to foster concrete deployment, project partners conducted laboratories focussing on case study areas, such as in Malta, Albania, Greece, Croatia and Cyprus, and, based on outcomes, provided tools as guidelines for BE planning. The resulting BE planning framework [6] concerns a methodological approach made by a sequence of stages to identify the most suitable sites for the installation of BE plants in target regions and include marine sources in the practices of maritime spatial planning.

The proposed methodology is specially conceived to be reliable, although based on approximations and assumptions, and provides scenarios of BE development to be discussed by local stakeholders. Rather than being definite solutions imposed by

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planners from the top downwards, the results of the BE planning process allow for engaging citizens, local communities and private businesses, which should be carefully supervised by local public authorities, to ensure that the introduction of new technologies harmonizes with already existing economic activities, and that possible conflicts among different productive sectors are managed, while complying with environmental legislation and integrated maritime policy [7].

The present paper shows an additional application of the already tested procedure of BE planning to the Giglio island (Tuscany, Italy). Although not systematically performed due to lack of site-specific information and data, a preliminary plan has been provided including suitable sites for different BE plants, their hypothetical size against physical, environmental and technical constraints, and an estimate of their potential effects in terms of energy production and carbon emission mitigation. Moreover, possible configurations in relation to coastal landscapes have been visualized. This study aims to show possible scenarios for the exploitation of marine energy sources on the island, engage public authorities, businesses and citizens in a participative design process, discuss limits and opportunities, and start a proactive debate around the renewable energy transition of the island.

2 Materials and Methods

The BE planning framework tested in the BLUE DEAL project combines interdisciplinary knowledge to integrate BE into strategic and operational plans in compliance with physical, regulatory, environmental, technical and social constraints that necessarily emerge in the Mediterranean area [6]. The planning procedure is structured into a sequence of six main stages:

Stage 1 – Identification of BE potentials. This concerns the spatial analysis of marine energy potentials including in particular wind (i.e. offshore wind speed) and wave energy (i.e. wave height and frequency). These data are accessible in the open source MAESTRALE webgis [8] and can be eventually studied in deep based on site-specific datasets, when available. The study of potentials allows for identifying the most profitable areas for the installation of offshore windmills or wave energy converters. Additional analyses concern the localization of existing aquacultural farms to be eventually coupled with systems exploiting marine biomass (e.g. algae biorefinery) to produce biofuels or biogas and the localization of desalinating plants to generate electricity through salinity gradients (e.g. reverse electro dialysis). An additional marine source is represented by the heat-cold exchange through electric seawater-based heat pumps for climate conditioning of coastal buildings. Marine currents are not a profitable source of energy in the Mediterranean.

Stage 2 – Identification of suitable BE technologies. BLUE DEAL provided a survey of existing BE technologies, their typologies ad size and the minimum requisites for their functioning [6]. For example, offshore wind turbines need minimum levels of wind speed and their installation is also conditioned to distance from the shore and bathymetric depth. Similar requisites are available for different wave energy converters depending on the technological typology. Given the early stage of development of BE technologies and their fast developmental rate in the last years, the survey of existing technology should be frequently updated in order to provide the correct information for BE planning.

Stage 3 – Identification of potential sites. The process of mapping is the crucial stage to identify potential sites for the installation of BE plants. This is based on the overlaying of spatially explicit data concerning energy potentials (stage 1), technological requisites (stage 2), and a series of exclusion zones, such as marine protected areas, posidonia meadows, shipping routes and port infrastructures, bird migration paths, operational areas of other marine activities (e.g fishing, diving, touristic facilities). This multiple-level spatial analysis results in the determination of limited areas that can be used as pilot sites for installation.

Stage 4 – Energy assessment. Outcomes from stage 3 determine available areas for different typologies of BE plants and their size and power. Planned scenarios can therefore be evaluated in terms of potential renewable energy production and this assessment also refers to the overall balance of the energy grid that is expected to integrate the energy supplied by intermittent marine sources. The forecasted energy production is conditioned by the available energy potentials and limited by the existing infrastructural grid. This energy assessment allows for estimating the energy production and the share of renewables in future scenarios.

Stage 5 – Carbon Footprint mitigation assessment. Avoided greenhouse gas emissions can be finally estimated considering the replacement of electricity from the grid with renewable sources. This assessment is based on values of the carbon intensity of electricity, such as comparing that of the national or local grid mix (for example, the carbon intensity of electricity from the national grid in Italy is 400.4 g CO_2eq/kWh [9]) with that of offshore wind turbines (i.e. average 49 g CO_2eq/kWh [10]) and wave energy converters (i.e. average 234 g CO_2eq/kWh for onshore systems; average 131.5 g CO_2eq/kWh for offshore systems; [11]) in the Mediterranean.

Stage 6 – Visual impact assessment. The representation of forecasted blue energy plants has a dual role, analysing the expected visual impacts and conditions of landscape compatibility depending on the size and density of devises and allowing for a deeper engagement of local stakeholders (Fig. 1).

The final outcome of the BE planning framework consists of a comprehensive BE plan with possible scenarios of BE deployment and quantitative estimates. Although any step can be eventually improved with additional and more detailed information, results show potential benefits in terms of energy self-sufficiency and carbon neutrality and also allows to start facing critical issues, including social acceptance, by sharing information with local stakeholders, policymakers, entrepreneurs and citizens.

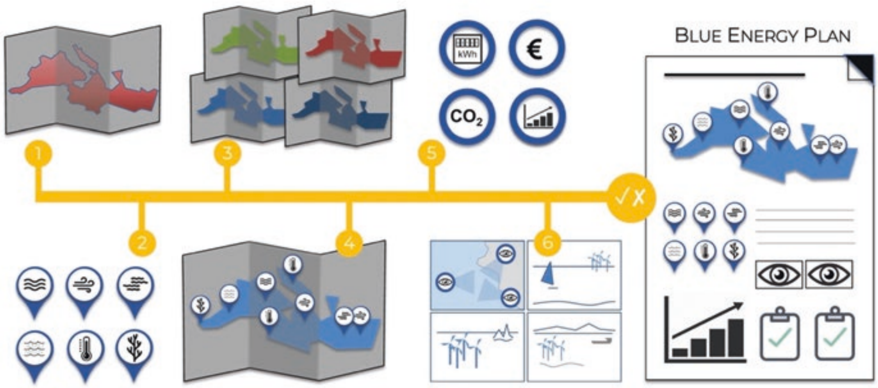

Fig. 1 Infographics of the Blue Energy Planning framework

3 Results and Discussion

The Giglio island has been taken as a case study to demonstrate how BE can drive the transition to renewable full electric systems in Mediterranean small islands. The island hosts 1345 inhabitants (ISTAT 2020) and 18,282 arrivals of tourists are recorded on an annual basis (ISTAT 2021), staying an average of 4.2 days per capita (i.e. total of 77,380 days/year). The electricity demand is 11,075 MWh/year and this is generated on the island by the thermoelectric power plant (10,300 MWh/year) supplied by diesel (around 860,000 kg/year), besides 775 MWh/year by PV. Data on electricity consumption per use (25% housing, 2% public lighting, 19% desalinating plant, 53% services, commercial and other uses) and per area (42% Giglio Porto, 39% Giglio Castello, 13% Campese, 2% Giannutri, 4% Rest of the island) is also useful to address policies of energy saving and eventually decrease the comprehensive demand.

Based on data on the current state (93% from fossil fuel) the greenhouse gas emission, hereafter Carbon Footprint (CF) of the energy system in the island is 5354 t CO_2eq/year (the current CIE value is 483 g CO_2eq/kWh). Table 1 shows the effects of the planned BE-based scenario which hypothesizes to fully replace fossil fuels with marine energy sources, particularly offshore wind and waves. The assessment considers the impact of BE technologies including 375 MWh/year generated by wave energy converters (e.g. oscillating water columns or oscillating floaters) installed in 150 m of existing docks, 3000 MWh/year generated by 75 near-shore buoys (e.g. three clusters of 25 each), and 6900 MWh/year generated by floating offshore wind turbines (e.g. three 1 MW wind turbines or one 3 MW turbine). The CF of the BE-based electrical system would be 847 t CO_2eq/year thus avoiding 84% of the impact (saved 4507 t CO_2eq/year). The new CIE value would be 76.5 g CO_2eq/kWh.

Table 1 Potential impact of a Blue Energy scenario in the Giglio island in terms of energy production and avoided carbon emission

	Quantity	CIE	CF	Note
Current state	MWh/ year	kg CO_2eq/ MWh	kg CO_2eq/ year	
Thermoelectric (diesel)	10,300	517.44	5,329,632	CIE [9]
PV	775	32	24,800	CIE [6]
Tot electricity production/use	11,075	**483.47**	**5,354,432**	
Scenario BE plan	MWh/ year	kg CO_2eq/ MWh	kg CO_2eq/ year	
Onshore wave energy converters	375	234.00	87,750	Installed 150 m dock; average 250 MWh/year per 100 m; CIE [11]
Offshore wave energy converters	3000	131.50	394,500	Installed 75 buoys; average 40 MWh/year per unit; CIE [11]
Offshore wind turbines	6900	49.20	339,480	Installed n.3 × 1 MW wind turbines; average 2300 MWh/year per unit; CIE [10]
PV	800	32	25,600	Almost 3% increase hypothesized.
Tot electricity production/use	11,075	**76.51**	**847,330**	
Avoided emission			**−4,507,102**	

The identification of potential pilot sites for the installation of BE technologies has been based on the BE planning framework and takes into account energy potentials (stage 1) and technical requisites of technologies (stage 2), besides physical, environmental and legal constraints (stage 3). This process would need anyhow deeper analysis based on site-specific data to be carefully monitored and therefore is not to be taken as properly verified or exhaustive. Similarly, the energy assessment (stage 4) does not take into account the energy balance of a hypothetical local smart grid managing the electricity generation by intermittent sources and variable electricity uses (e.g. consistent changes due to seasonal tourism) necessarily embedding energy storages. The impact of BE technologies (stage 5) should be also assessed based on site-specific data on the energy production of devices in given locations to be specifically monitored. Figure 2 shows the pilot sites hosting BE technologies on the island (left side); besides wind turbines and wave energy converters, it also shows BE technologies to be potentially combined with the desalinating plant (reverse electro dialysis) and tourist infrastructures (seawater-based heat pumps). Moreover, it shows the Giglio Porto and visualization of BE devices in that area (right side).

Fig. 2 Pan for installation of BE technologies and visualization* of the Giglio Porto pilot site. (*View made by Alessio Sabbetta. MSc Thesis in Landscape Architecture)

4 Conclusion

The Blue Energy planning framework described in this paper has been developed under the scope of the Interreg Med BLUE DEAL project to promote the deployment of Blue Energy technologies in the Mediterranean region and support their inclusion in Maritime Spatial Planning initiatives.

The methodology has been here applied to Giglio Island to preliminarily identify potential sites for the installation of different BE technologies, dimensioning possible interventions and assessing potential outputs and impacts. Results show a possible scenario of energy transition of the island, ideally fully supplied by marine renewable sources.

The plan identifies suitable solutions and potential sites taking into account energy potentials, technical requisites of BE technologies, legal constraints, possible interferences with other maritime activities and environmental and landscape impacts. Nevertheless, outcomes are based on assumptions and approximations and, far from being definite and exhaustive, are conceived as preliminary hypothesis to start a discussion among local administrators, businesses and citizens.

Through open consultation with local stakeholders, it would be possible to anticipate causes of resistance against the deployment of Blue Energies and proactively address emerging problems, thus making steps forward in the social acceptance, and concretely contribute to foster the energy transition of Mediterranean islands.

References

1. IPCC. (2022). Climate change 2022 impacts, adaptation and vulnerability. Contribution of Working Group II to the sixth Assessment Report of the Intergovernmental Panel on Climate Change.
2. Fries, S. (2021). *Transforming energy systems: Economics, policies and change*. Edward Elgar Publishing.
3. Petit, V. (2018). *The new world of utilities: A historical transition towards a new energy system*. Springer.
4. MAESTRALE. (2017–2019). Interreg Med project official website: https://maestrale.interreg-med.eu
5. BLUE DEAL. (2019–2022). Interreg Med project official website: https://blue-deal.interreg-med.eu
6. Pulselli, R. M., Struglia, M. V., Maccanti, M., Bruno, M., Patrizi, N., Neri, E., Carillo, A., Napolitano, E., Stefanatos, N., Perakis, C., Damasiotis, M., Di Pietrantonio, F., Magaudda, S., Madalena, V., Stančin, H., Mikulčić, H., Petrou, V., Smagas, K., Valari, E., Shakou, L. U., & Bastianoni, S. (2022). Integrating blue energy in maritime spatial planning of Mediterranean regions. *Frontiers in Energy Research, 10*, 939961. https://doi.org/10.3389/fenrg.2022.939961
7. Batianoni, S., Praticò, C., Damasiotis, M., & Pulselli, R. M. (2020). Perspectives for marine energy in the Mediterranean area. Frontiers in Energy Research. Editorial article 09 September 2020. https://doi.org/10.3389/fenrg.2020.00209
8. MAESTRALE webgis. Available at: http://maestrale-webgis.unisi.it
9. ISPRA, 2022[b]. Indicatori di efficienza e decarbonizzazione del sistema energetico nazionale e del settore elettrico. Report 363/2022. Available at: https://www.isprambiente.gov.it/files2022/pubblicazioni/rapporti/r363-2022.pdf
10. Pulselli, R. M., Maccanti, M., Bruno, M., Sabbetta, A., Neri, E., Patrizi, N., & Bastianoni, S. (2022). Benchmarking marine energy technologies through LCA: Offshore floating wind farms in the Mediterranean. *Frontiers in Energy Research, 10*, 902021. https://doi.org/10.3389/fenrg.2022.902021
11. Bruno, M., Maccanti, M., Pulselli, R. M., Sabbetta, A., Neri, E., Patrizi, N., & Bastianoni, S. (2022). Benchmarking marine energy technologies through LCA: Wave energy converters in the Mediterranean. *Frontiers in Energy Research, 10*, 980557. https://doi.org/10.3389/fenrg.2022.980557

Part IV
Humans: Environmental Comfort and Well-Being, Energy Efficiency and Users' Conscious Behaviour

Evaluation of Electrical Performance for 1.4 kW Photovoltaic System in Oman: A Technical and Economic Study

Hussein A. Kazem

1 Introduction

Today, most energy is produced from non-renewable energies such as coal, oil, and natural gas, which are fossil sources that have negative effects on the environment and public health [1, 2]. Renewable energies have many resources, such as wind, ocean, and solar, and there are much more. Solar energy is one such resource which is usually either solar cell technology or solar concentrators. Solar energy is one of the best types of renewable energy for generating electricity using photovoltaic cells. Photovoltaic cells still face some important problems that limit their spread, such as their high cost and sometimes low efficiency [3]. Furthermore, the output power of PV systems is not stable throughout their operating time, which reduces their power generation reliability for the user. The unstable amount of energy can be due to differences in radiation which can cause poor performance of the electrical network [4]. It is necessary to look at the economic aspect of installing a PV system due to the cost of utilities which is reflected in the price of energy produced.

Two types of photovoltaic systems are used today: Standalone photovoltaic system, which is used for simple applications such as water pumping and water spraying [5]. Such a system works with or without battery storage as it operates for a fixed and limited period. The cost of the system without a battery is lower compared to other systems [6]. The second system is a grid-connected solar PV system, which is connected to the electricity generation system. The system includes rooftop-mounted solar modules, inverter, power conditioning unit, and grid-connected equipment. The system is usually used in residential areas [7].

Much research conducted to investigate grid-connected photovoltaic systems.

Kazem et al. [8] provided a model and assessment of a grid-connected photovoltaic system that was set up in the city of Sohar in the Sultanate of Oman. The study focused on solar radiation and ambient temperature data for 12 months. The

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modeled system is installed practically and examined for half a year to make sure its feasibility and productivity. The system is designed by using three technical criteria which are yield, performance, and capacity factors. Also, the feasibility of the system is considered in terms period of payback and energy cost. The evaluated data for 12 months shows that yield and capacity factors for the designed model are 21% p/year and 1875 kW h/kW. Furthermore, the designed system performance factor is 84.6%. On the other hand, the period of payback and the energy cost producer of the designed system is 11 years and 0.045 USD/kW h respectively.

A. Al-Badi [9] evaluated the measured data of a 1.4 kW grid-connected photovoltaic system. The main objective was to evaluate the PV performance of desert types in Muscat weather conditions. The system is designed by using many technical criteria which include the ratio of performance, factor of capacity, and various types of PV system yields and losses. Cardona and Lopez [10] assess the data acquired in the evaluation of a 2 kW grid-connected PV system in the city of Malaga in Spain. The result was examined from January to December in the year 1997. The losses of the energy of the proposed model and installation performances were considered. The model powered 2678 kWh to the grid, with daily energy of 7.4 kWh, with a monthly efficiency of the system around 8% and 6.1%.

Al-Sabounchi et al. [11] installed and designed PV grid-connected system with 36 kW at a level of 0.4 kV in Abu Dhabi, UAE. The system is designed by using many technical criteria which include the production of energy, output power, the efficiency of conversion, frequency and voltage consistency, accumulation of dust, and temperature. The result showed that system operation conversion efficiency is moderate even with the condition of high temperature at the setup location. While the accumulation of dust decreases the PV system performance.

Humada et al. [12] investigated the impact of three parameters in the tropical climate conditions of Malaysia. These parameters were the PV grid-connected system characterization, development, and performance. The result obtained by simulation revealed that the PV system performance and efficiency of performance of inverter were 65.8% and 97.58% respectively. The model's accuracy was proved by using various criteria of evaluation and compared with many systems from the legacy works. Kazem and Khatib [13] studied a techno-economical procedure to examine the grid-connected PV system in terms of productivity in the city of Sohar in the Sultanate of Oman. Tahria et al. [14] analyzed grid-connected PV systems based on two types of technologies of photovoltaic designs. The study showed 12 months' data of four modules of grid-connected PV systems were set up in Tsukuba in Japan which are two multicrystalline technologies and two thin-film technologies.

The electrical performance of a grid-connected photovoltaic system is affected by many factors such as temperature, wind, dust, and humidity [15]. This study aims to investigate these factors which can impact voltage and current and then affect output power, which yields on the technical side as well economic respective. The objectives of this study can be summarized as (1) To investigate the operation of a 1.4 kW multi-crystalline grid-connected photovoltaic system in Sohar. (2) To measure and evaluate the performance values for the photovoltaic system. (3) To evaluate photovoltaic grid-connected system productivity in Sohar in terms of technical and economic aspects.

2 Methodology

2.1 Study Area

The Sultanate of Oman, which covers an area of 309,500 km^2 lies north between the latitudes 16° 40′ and 26° 20′ and east between the longitudes 51° 50′ and 59° 40′. Figure 1 refers to the Sultanate of Oman map, which shows its strategic and distinguishes location which allows it to have many different renewable energy resources [16].

The Sultanate of Oman contains many sources of income such as oil and natural gas and oil. In 2012, oil contributed about 64% of the country's revenues. The Sultanate of Oman stated that it has around 5.2 billion barrels of oil. On the other hand, natural gas is considered the main source of revenue for the Sultanate of Oman, which is the largest and most important sector, wherein 1 year 29 billion cubic meters were sold [17]. The Sultanate of Oman began to search for different, clean, and alternative energies such as wind energy and solar energy because gas and oil will not become stable sources of income and energy in the near and present future. In recent years, the Sultanate of Oman has started to use and install various renewable energy projects [18]. That's why many oil and gas countries started to consider working on renewable energy projects such as solar energy [19].

Fig. 1 Sultanate of Oman map [16]

2.2 Experimental Setup

The experiments were conducted on a grid-connected system installed on the roof of a solar energy laboratory at Sohar University. Figure 2 shows a photo of the used system. The photovoltaic solar modular used in the system is (KD 140GH-2P) model that provides peak power of (140 W) in the condition of voltage at the nominal status of 12 V DC. Solar panels are installed at a determined tilt angle of site latitude +3 facing the direction of true south in order to expand the average output power annually [20]. The panels are connected in series in order to supply sufficient input voltage to the grid tie inverter. Table 1 lists the studied system specifications while Table 2 illustrates the grid-connected system specifications. Table 3 shows the costs of the individual parts of the system and the total one.

The criteria to evaluate the grid-connected photovoltaic system can be done through several equations, which are:

- Energy Production (E) and Energy Yields (SY)

$$\mathrm{YFd} = \frac{\mathrm{EPV}\left(\frac{\mathrm{kWh}}{\mathrm{year}}\right)}{\mathrm{PVWP}\left(\mathrm{KWp}\right)} \tag{1}$$

Fig. 2 Installed PV system

Table 1 PV module details

Electrical performance	Dimensions	Cells	General info
PV module type is (KD140GH-2PU) At 1000 (W/M^2) Max power 140 (W). Max voltage of system 1000 (V). Max voltage of power 17.7 (V). Max current of power 7.91 (A). Open circuit voltage 22.1 (V). Short circuit current 8.68 (A). Efficiency 13.9 (%). At 800 (W/M^2) Max power 101 (W). Max voltage of power 16.0 (V). Maximum current of power 6.33 (A). Open circuit voltage 20.2 (V). Short circuit current 7.03 (A). Power tolerance +5/–5 (%). Max reverse current 15 (A). Series fuse rating A 15 Coefficient of temperature VOC 0.36 (%/K). Coefficient of temperature ISC 0.06 (%/K). Coefficient of temperature –max power- –0.46 (%/K). Efficiency reduction (1000–200) W/m^2.	Length is 1500 mm (±2.5). Width is 668 mm (±2.5). Depth/incl. junction box is 46 mm. Weight is 12.5 kg. Cable (+)1010/(−)840 mm. Connection type is (MC PV-KBT3/MC PV-KST3). Junction box is (113 × 82 × 15) mm. Bypass diodes are 2. IP code is (IP65).	Number in each module is 36 cells Type is polycrystalline cell. Shape is “square” (156 × 156) mm.	Guarantee performance (10–20 years). Warranty (5 years)

Table 2 Specifications of the proposed system

PV module rated power (10 modules)	140 Wp (1.4 kWp)
Voltage (Maximum)	17.7 (V)
Current (Maximum)	7.91 (I)
Voltage of open circuit	22.1 (V)
Current of short circuit	8.68 (I)
Efficiency of PV module	13.9 (%)
Vo.c temperature coefficient	−0.36 (%/K)
Is.c temperature coefficient	0.06 (%/K)
Inverter	1 (kw)
AC voltage	220–260 (V)
Efficiency of inverter	94.1 (%)

Table 3 Proposed system cost

Item	Unit price	Price ($)
Array of PV 10 × 140 Wp	3.8 USD/Wp	5320.00 USD
Circuit breakers, cables, and support structure.	–	1600.00 USD
Inverter (1.7 kW)	1500.00 USD	1500.00 USD
Installation	–	1600.00 USD
The Total		10,020.00 USD

$$\text{YFF} = \frac{\text{EAC}\left(\frac{\text{kWh}}{\text{year}}\right)}{\text{PVWP}\left(\text{kWP}\right)} \tag{2}$$

$$\text{YR} = \frac{\text{GT}}{\text{GSTC}} \tag{3}$$

- Cost of Energy (CoE)

$$\text{CoE} = \frac{\text{LCC}}{\sum_{1}^{N}\text{Epv}} \tag{4}$$

- Performance Ratio (R)

$$\text{PR} = \frac{\text{SY}}{\text{YR}} \tag{5}$$

- Life Cycle Costs (LCC)

$$\text{LCC} = \text{Ccapital} + \sum_{1}^{n}\text{Co}\,\&\,\text{m.Rpw} + \sum_{1}^{n}\text{Creplacemant.Rpw} - \text{Csalvage.Rpw} \tag{6}$$

$$\text{Rpw} = F/\left(1+i\right)^{N}$$

$$\text{Ccapital} = \text{CAi} \times \text{UCi} \times \text{ICI}$$

- Percentage Value of the Replacement Cost (RC)

$$\text{RC} = \sum_{K=1}^{2}\text{RCk} \tag{7}$$

$$\mathrm{RCk} = \mathrm{ICk} \times \sum_{j=1}^{\mathrm{Nr}} \left(\frac{1+\mathrm{FR}}{1+\mathrm{IR}} \right)^{\left(\frac{\mathrm{LP}\times j}{\mathrm{Nr}+1} \right)}$$

- Present Worth (MC)

$$\mathrm{MC} = \sum_{1}^{r} \mathrm{MCr} \tag{8}$$

$$\mathrm{MCr} = \mathrm{MC0r} \times \left(\frac{1+f}{i-f} \right) \times \left[1 - \left(\frac{1+f}{1+i} \right)^{N} \right]$$

$$\mathrm{MC0r} = \mathrm{Kr} \times \mathrm{ICr}$$

- Capacity Factor (CF)

$$\mathrm{CF} = \frac{\mathrm{SY}}{8760} = \frac{\mathrm{Epv\,annnal}}{(\mathrm{PR} \times 8760)} \tag{9}$$

3 Results and Discussions

The experiment was conducted from 3rd April 2019 to 2nd May 2019 every day from 6:00 am to 6:30 pm, where the system records data every 15 minutes. The data recorded is provided by Microsoft Excel. This recorded data is analyzed to evaluate the grid-connected system performance and yield.

Figure 3 illustrates the plot of energy (kWh) consumed per day which in short has risen from 648 (kWh) gradually until it reached 700 (kWh) within 3 weeks and 4 days. The energy remained relatively stable at 790 (kWh) for 2 days 26th and 27th of April. On 29th April the energy consumed decreased to 691 (kWh) and started to increase steadily to the highest amount of energy about 831 (kWh) at the beginning of May. This variation in the energy consumed with days can be referred to as increasing electricity demand depending on ambient temperature. During this period (April and May) the seasons change from spring to summer and increase the ambient temperature, which recall using more air conditioning systems and increase the energy consumption.

Figure 4 shows the output AC current correlation with time per day for the 4 weeks and 1 day exactly. The output begins at the highest degree 2532 (mA) and decreased to 1252 (mA) on 1st May which is about half or less than the starting amount. However, the lowest amount over the span appeared on 21 of April when the AC current decreased dramatically from 2120 (mA) to only 484.7 (mA). There are two reasons for these decrements: the first is the ambient temperature increase,

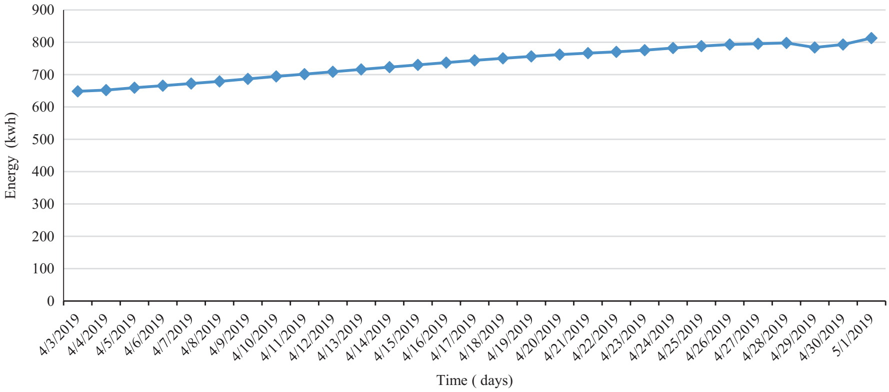

Fig. 3 The energy consumption through the studied period

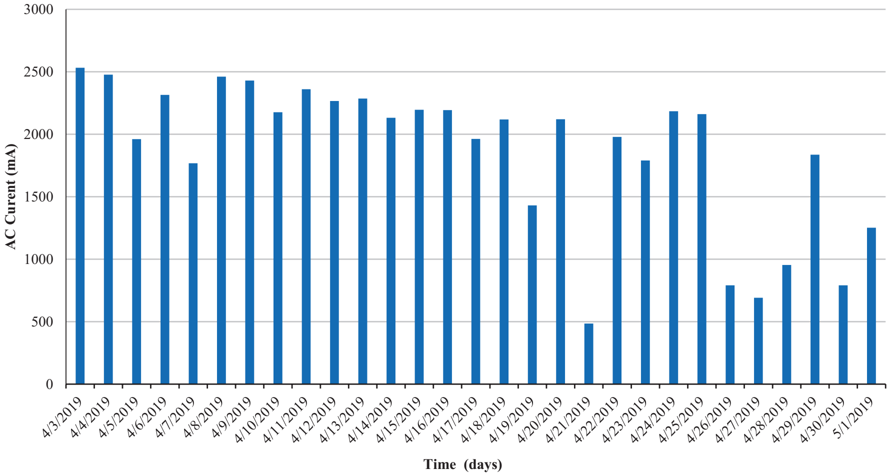

Fig. 4 The recorded AC current through the study days

and the solar radiation increase also, which affected the solar modules currents. The second is the sky (21 April), which reduced the solar irradiance and reached the modules.

Figure 5 describes the relationship between the outputs of the AC voltage and time. The amount of the AC voltage dramatically decreased to 246 (V) which is the lowest output during this period. On 26th April, it reached the highest voltage value of 251 V. After fluctuating for 2 weeks the AC voltage increased sharply to reach the highest amount of 251 V. Then, it decreased again dramatically and again went up to the previous amount of 251 V. This voltage fluctuation depends mainly on the module temperature that affects the module productivity with the interference of other parameters such as wind speed and humidity as well as dust [21].

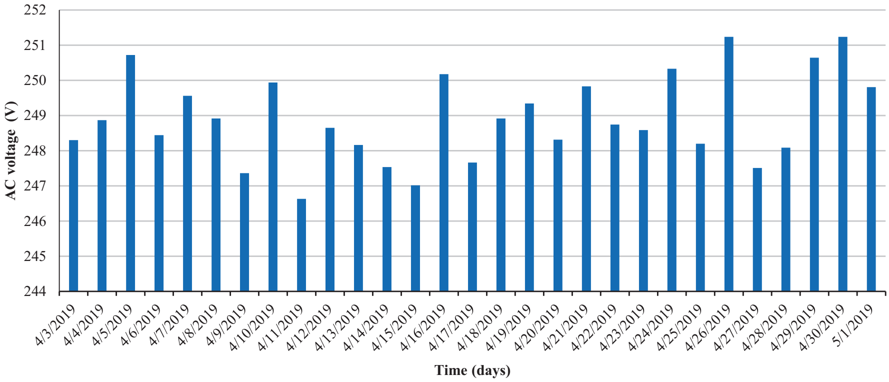

Fig. 5 The recorded AC voltage through the study days

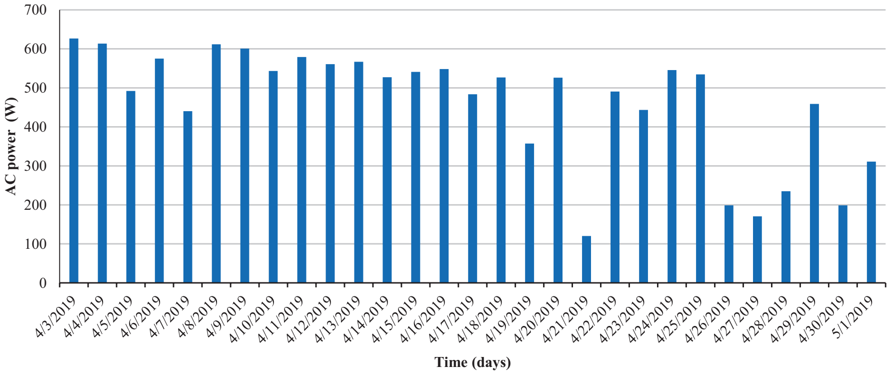

Fig. 6 The recorded AC power through the study days

Figure 6 shows the relationship between the AC power through the study time (between the 3th of April until 1st of May). During this period the moment of AC power quantity is changed. On the first day, the power is around 630 W which was good, and between the second day and day 18, the AC power was fairly close from 610 to 450 W. After that, the power dropped very high to 120 W, then it started to increase again to 500 W. During the last study days, changes in the generated AC power between increase and decrease were observed. Power is the product of current multiplied by voltage, and therefore any fluctuation of either or both cause such a result. This is what is observed in Figs. 4 and 5. From the above figures, it can be seen that the DC to AC conversion losses by the inverter are very limited. The reason for this is that the efficiency of the inverter is high.

The equations above were used to find the system criteria. The yield factor is defined as the output of photovoltaic energy of the system (annual, monthly or daily) divided by the peak power. In this study, 30 days are considered to evaluate from 3rd April 2019 to 2nd May 2019, and the annual production of energy is found 2625.18 kWh.

- Yield factor in 1 year $\text{YF} = \frac{2625.18\,\text{kWh}/1}{1.4\,\text{kW}} = 1875.128\,\text{kWh}/\text{kWp year}$

- Yield factor in 1 month $\text{YF} = \frac{2625.18\,\text{kWh}/12}{1.4\,\text{kW}} = 156.260\,\text{kWh}/\text{kWp month}$

- Yield factor in 1 day $\text{YF} = \frac{2625.18\,\text{kWh}/365}{1.4\,\text{kW}} = 5.137\,\text{kWh}/\text{kWp day}$

The capacity factor (CF) of the system is defined as the ratio between the output of actual annual energy to PV array energy amount that would be generated if it operates at full rated power for a full day for a year.

$$\text{CF} = \frac{\text{SY}}{8760} = \frac{\text{Epv annnal}}{(\text{PR} \times 8760)} = \frac{2625.18}{(1.4 \times 8760)} = 0.214 = 21.4\%$$

The Optimum Sizing Ratio of the Inverter (Rs) is the ratio of the photovoltaic array-rated power to the inverter-rated power. It refers to the efficiency of maximum average conversion, which was for the studied system for the studied period:

$$\text{Rs} = \frac{\text{PV array rated power}}{\text{inverter rated power}} = \frac{1.4\,\text{kW}}{1.7\,\text{kW}} = 0.823 = 82.3\%$$

Life Cycle Cost (LCC) represents the cost for the proposed system, permits, site preparation, installation labor, maintenance, and operation costs.

$$\text{LCC} = \text{Ccapital} + \sum_{1}^{n} \text{Co \& m.Rpw} + \sum_{1}^{n} \text{Creplacemant.Rpw} - \text{Csalvage.Rpw}$$

$$\text{LCC} = 2953.3275\,\text{USD}$$

The system Cost of Energy (CoE)

$$\text{CoE} = \frac{\text{LCC}}{\sum_{1}^{N} \text{Epv}}$$

Where Epv annual is the yearly energy production of the photovoltaic system, while (*N*) refers to the system lifetime in years.

$$\text{CoE} = \frac{2953.3275}{\sum_{1}^{25} 2625.18} = 0.045\,\text{USD}/\text{kWh}$$

The system Payback Period (PBP) is

$$\text{PBP} = \frac{\text{Ccapital}\left(\text{USD}\right)}{\text{Epv annnal} \times \text{CoE}\left(\text{USD / kWh}\right) \times \text{RPW]}} = 0.045\,\text{USD / kWh}$$

Where

$$\text{Rpw} = F / \left(1 + i\right)^{N}$$

$$\text{PBP} = 11.17\,\text{years}$$

$$\text{Cost of Electricity Usage} = \text{Rate} \times \text{Energy}$$

$$\text{Energy} = \text{Power} \times \text{time} = 1.4 \times 12 = 16.8\,\text{kWh}$$

$$\text{Cost} = 0.181 \times 16.8 = 3.0408\,\text{USD}$$

The photovoltaic system was evaluated based on two criteria: Technical parameters and Economic Standards. The yield factor was used to assess the productivity of the system. There is no typical production factor, but instead each region or country has its factor of production, such as Japan's typical production factor of 470–1230 kWh/kW/year and about 400–1300 kWh/kW/year in Germany. The typical production factor of Oman is about 1875.132 kWh/kWh/year which means that it has almost the best performance compared to other regions around the world, and the yield factor of the system in 1 year is 1875.128 kWh/kWh/year which proves and indicates that PV technology is considered in Oman is the best performer compared to other regions around the world. Besides, the optimum size ratio of the inverter is 82.3%. Whereas the cost factor is a technical standard that has been used to calculate the use of an energy source. It is found that the maximum real cost factor is 0.5 and the typical cost factor of the PV system lies in the range of 0.214 which indicates that the system is operating in a typical operating area.

Whereas the economic evaluation criteria of life cycle cost which found $2953.3275 while energy cost found 0.045 USD/kWh worth considering the cost without government subsidy is 0.181 USD/kWh while the energy utilization cost is $3.0408, and the payback period is 11.17 years which is a good investment period.

4 Conclusions

The present study focused on evaluating the electrical performance of a grid-connected photovoltaic system with a capacity of 1.4 kW in Oman (experiments were conducted at Sohar University located in Sohar City). The system's measuring devices were used to record its variables of current, voltage, and power every quarter of an hour per day for a whole month. The electrical performance of the studied photovoltaic system was analyzed. The results showed that the system can work in harsh conditions in Oman, where the air temperatures are high, and the relative humidity is also high. The system's productivity of AC electricity was adequate, and losses were few. Also, an economic study of the system showed that the possibility of recovering the invested capital will not exceed 11 years, which is an appropriate period.

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References

1. Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews, 39*, 748–764.
2. Chaichan, M. T., Kazem, H. A., & Abed, T. A. (2018). Traffic and outdoor air pollution levels near highways in Baghdad, Iraq. *Environment, Development and Sustainability, 20*(2), 589–603.
3. Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. *Renewable and Sustainable Energy Reviews, 15*(3), 1513–1524.
4. Kazem, H. A. (2016). Photovoltaic solar thermal (PV/T) collectors past, present and future: A review. *International Journal of Applied Engineering Research, 11*(22), 10757–10765.
5. Kazem, H. A., Al-Waeli, A. H., Chaichan, M. T., Al-Mamari, A. S., & Al-Kabi, A. H. (2017). Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman. *Environment, Development and Sustainability, 19*(3), 1041–1053.
6. Good, C., Andresen, I., & Hestnes, A. G. (2015). Solar energy for net zero energy buildings–A comparison between solar thermal, PV and photovoltaic–thermal (PV/T) systems. *Solar Energy, 122*, 986–996.
7. Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H., & Sopian, K. (2020). A novel model and experimental validation of dust impact on grid-connected photovoltaic system performance in Northern Oman. *Solar Energy, 206*, 564–578.
8. Kazem, H. A., Khatib, T., Sopian, K., & Elmenreich, W. (2014). Performance and feasibility assessment of a 1.4 kW roof top grid-connected photovoltaic power system under desertic weather conditions. *Energy and Buildings, 82*, 123–129.
9. Al-Badi, A. H. (2018). Measured performance evaluation of a 1.4 kW grid connected desert type PV in Oman. *Energy for Sustainable Development, 47*, 107–113.
10. Sidrach-de-Cardona, M., & Lopez, L. M. (1998). Evaluation of a grid-connected photovoltaic system in southern Spain. *Renewable Energy, 15*(1–4), 527–530.
11. Al-Sabounchi, A. M., Yalyali, S. A., & Al-Thani, H. A. (2013). Design and performance evaluation of a photovoltaic grid-connected system in hot weather conditions. *Renewable Energy, 53*, 71–78.
12. Humada, A. M., Aaref, A. M., Hamada, H. M., Sulaiman, M. H., Amin, N., & Mekhilef, S. (2018). Modeling and characterization of a grid-connected photovoltaic system under tropical climate conditions. *Renewable and Sustainable Energy Reviews, 82*, 2094–2105.
13. Kazem, H. A., & Khatib, T. (2013). Techno-economical assessment of grid connected photovoltaic power systems productivity in Sohar, Oman. *Sustainable Energy Technologies and Assessments, 3*, 61–65.
14. Tahri, F., Tahri, A., & Oozeki, T. (2018). Performance evaluation of grid-connected photovoltaic systems based on two photovoltaic module technologies under tropical climate conditions. *Energy Conversion and Management, 165*, 244–252.

15. Al-Waeli, A. H., Kazem, H. A., Chaichan, M. T., & Sopian, K. (2019). *Photovoltaic/thermal (PV/T) systems: Principles, design, and applications*. Springer Nature.
16. Yousif, J. H., Al-Balushi, H. A., Kazem, H. A., & Chaichan, M. T. (2019). Analysis and forecasting of weather conditions in Oman for renewable energy applications. *Case Studies in Thermal Engineering, 13*, 100355.
17. Al-Maamary, H. M., Kazem, H. A., & Chaichan, M. T. (2017). The impact of oil price fluctuations on common renewable energies in GCC countries. *Renewable and Sustainable Energy Reviews, 75*, 989–1007.
18. Kazem, H. A., Al-Waeli, A. H., Chaichan, M. T., Al-Waeli, K. H., Al-Aasam, A. B., & Sopian, K. (2020). Evaluation and comparison of different flow configurations PVT systems in Oman: A numerical and experimental investigation. *Solar Energy, 208*, 58–88.
19. Al-Maamary, H. M., Kazem, H. A., & Chaichan, M. T. (2017). Climate change: The game changer in the Gulf Cooperation Council Region. *Renewable and Sustainable Energy Reviews, 76*, 555–576.
20. Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H., & Sopian, K. (2022). Evaluation of Omani experience in using grid-connected photovoltaic stations. In *Sustainable energy development and innovation* (pp. 53–59). Springer.
21. Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H., & Sopian, K. (2021). Preprint: Evaluation of aging and performance of grid-connected photovoltaic system northern Oman: Seven years' experimental study. *Solar Energy, 207*, 1247–1258.

Rethinking the European Green Deal: Accelerating the Transformation Toward Energy Independence Based on 100% Renewable Energy

Rainer Hinrichs-Rahlwes

1 Introduction

When the present European Commission (EC) took office on 1 December 2019, the *European Green Deal* was announced as one of their lighthouse projects. In her Mission Letter, Commission President Ursula von der Leyen entrusted Frans Timmermans with the role of Executive Vice-President for the *European Green Deal* and responsible for the climate action portfolio [1]. He became responsible for leading a group of Commissioners tasked with developing and implementing *"Europe's hallmark"*. The main elements of the European Green Deal are outlined in the letter: *"At the heart of it is our commitment to becoming the world's first climate-neutral continent. It will require collective ambition, political leadership and a just transition for the most affected"*. A number of legislative and non-legislative proposals were already presented in the first 100 days of the new Commission: a *European Climate Law* should enshrine the commitment to become climate neutral by 2050 and therefore increase the EU's greenhouse gas reduction target for 2030 from 40% to *"at least 50%"*. An increase to 55% was considered. A *Just Transition Fund* shall protect regions and people which are most affected by the transformation towards carbon neutrality. And *"tax policies enable us to deliver on our climate ambitions. This will include the work on the Carbon Border Tax, as well as the review of the Energy Taxation Directive"*. Implementation of existing instruments like the Emissions Trading System (ETS) [2] and the Effort Sharing Directive (ESD) [3] should be assured and enhanced. A *European Climate Pact* shall be developed *"bringing together regions, local communities, civil society, industry and*

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schools. Together they will design and commit to a set of pledges to change behaviours across our society". More details of the *European Green Deal* were published with the *Commission Work Programme 2020* [4] some proposals were already subject to public consultations and feedback loops and some were officially presented to the European Council and the European Parliament for consideration and – where appropriate – adoption.

2 Objectives of the European Green Deal

From the beginning, the EC underlined the high priority of the *European Green Deal*. An EC Communication of *the European Green Deal* [5] was published only 10 days after the new Commission had taken office, the initial *Commission Work Programme* highlighted the *Green Deal* as the first of *"six headline ambitions",* branding it (in **bold letters**) as the solution for the global challenges of climate change, biodiversity loss, security and prosperity. *"**The European Green Deal is our new growth strategy**. It will help create jobs and make Europe more competitive globally. Our new industrial strategy will be essential in making this happen as an enabler of both the ecological and digital transitions"*. The ambition is high: *"The European Green Deal provides a roadmap with policies and measures to deliver the transformative change we need across all sectors"*. As a first major deliverable, the *European Climate Law* shall enshrine the objective of climate neutrality by 2050 and it will be accompanied by proposals for higher *"EU ambition to reduce greenhouse gas emissions by 2030"*.

There are a *"Strategy for Smart Sector Integration and a Renovation Wave"* and proposals for better exploiting *"Europe's offshore renewable energy"* and a *"Strategy for Sustainable and Smart Mobility",* a *"new EU Biodiversity Strategy for 2030"* and a *"'Farm to Fork' Strategy"*. To provide sufficient financing the EC also proposed a *"European Green Deal Investment Plan"* and a *"Renewed Sustainable Finance Strategy"*, which – together with a *"Just Transition Mechanism"* and a *"Just Transition Fund"* – should help the most affected regions and sectors. In addition, a *"European Climate Pact"* should be developed. It *"will bring together all of these efforts, involving regions, local communities, civil society, schools, industry and individuals"*.

Strategic considerations and context are provided in the Communication [5]. It aims at including a broad range of policy areas, such as health, environment, social justice, energy, climate change and sustainable development. It is designed to be *"an integral part of this Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals"* [6].

Figure 1 provides an illustration of the context and the various elements. The most important ones for this paper are *"Increasing the EU's climate ambition for 2030 and 2050"*, *"Supplying clean, affordable and secure energy", "Mobilising industry for a clean and circular economy", "Building and renovating in an energy and resource-efficient way", "Accelerating the shift to sustainable and*

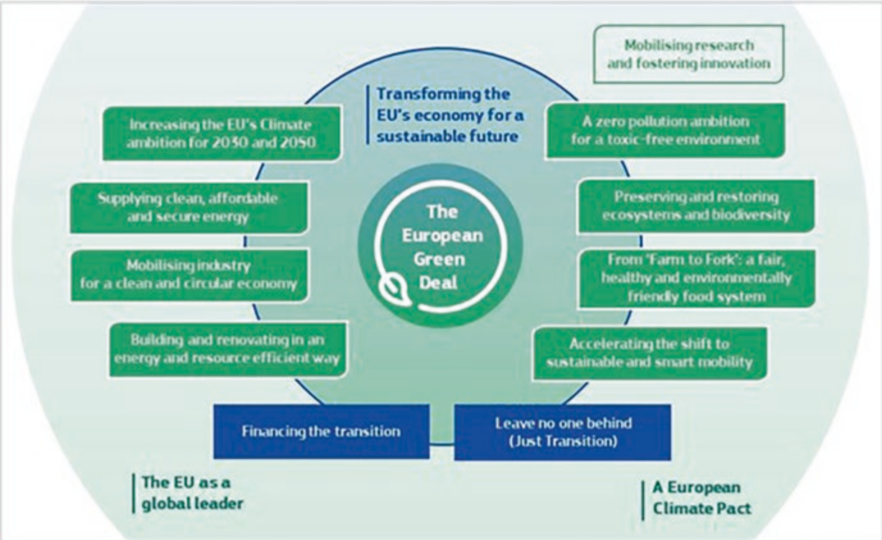

Fig. 1 The European Green Dea. (Source: European Commission [5])

smart mobility", and the overarching approach of *"Mainstreaming sustainability in all EU policies"*.

The EC announces a *"plan to increase the EU's greenhouse gas emission reductions target for 2030 to at least 50% and towards 55% compared with 1990 levels in a responsible way"*. This is significantly more than the existing 40%-target, but far below a 65% reduction, which NGOs, Greens and several other Members of the European Parliament are suggesting for being in line with the Paris Agreement. Given that, energy accounts for more than 75% of the EU's greenhouse gas emissions prioritizing energy efficiency are highlighted. For the supply side, a *"power sector must be developed that is based largely on renewable sources, complemented by the rapid phasing out of coal and decarbonising gas"* – a strong, but ambiguous statement, which leaves room for Member States to pursue their own priorities, not all which are sustainable.

The new *EU industrial strategy* was adopted in March 2020 [7]. For significantly accelerating sustainable building and renovation of buildings, the EC plans to *"engage in a 'renovation wave' of public and private buildings"* and to *"rigorously enforce the legislation related to the energy performance of buildings"*. A *"strategy for sustainable and smart mobility"* is planned to be adopted in 2020. Policies and strategies to *"ramp-up the production and deployment of sustainable alternative transport fuels"* and *"striving for drastically less polluting"* transport, especially in cities are key objectives of the new EC.

"Mainstreaming sustainability in all EU policies" is focusing on financial aspects. The EC estimates *"that achieving the current 2030 climate and energy targets will require €260 billion of additional annual investment, about 1.5% of 2018 GDP"*. A *Sustainable Europe Investment Plan* will be presented, as well as a

Just Transition Mechanism, including a *Just Transition Fund*. Well-designed tax reforms will help boost sustainable growth and ensure that national budgets follow the priorities of the *European Green Deal*. A *European Climate Pact* shall involve citizens and stakeholders in discussing, developing, and strengthening activities. A public consultation [10] about preferred activities for the *Climate Pact* is ongoing.

3 Components of the European Green Deal

The draft *European Climate Law,* the *Just Transition Mechanism* and *Fund,* the *European Climate Pact*, and the *Industry Strategy* were the first elements to be presented for public consultations and the legislative process.

The proposal for a ***European Climate Law*** [11] was presented just before the end of the EC's first 100 days in office. Building on the headline target to become a climate-neutral continent by 2050, and on a Communication from the predecessor Commission of November 2018 [12], the *"proposal aims to complement the existing policy framework by setting the long-term direction of travel and enshrining the 2050 climate-neutrality objective in EU law, enhancing adaptation efforts, establishing a process to set out and review a trajectory until 2050, regular assessment and a process in case of insufficient progress or inconsistencies"*.

Article 1 sets out *"a binding objective of climate neutrality in the Union by 2050"*. *Article 2* defines the process towards increasing the EU's 2020 reduction target: *"By September 2020, the Commission shall review the Union's 2030 target for climate […] in light of the climate-neutrality objective […], and explore options for a new 2030 target of 50 to 55% emission reductions compared to 1990. Where the Commission considers that it is necessary to amend that target, it shall make proposals to the European Parliament and to the Council as appropriate … By 30 June 2021, the Commission shall assess how the Union legislation […] would need to be amended […]"*.

Article 3 introduces a potentially strong instrument for the EC to steer towards climate neutrality, which was seldom used in climate and energy policy so far. *"1. The Commission is empowered to adopt delegated acts […] by setting out a trajectory at the Union level to achieve the climate-neutrality objective […] until 2050. At the latest within six months after each global stocktake […] of the Paris Agreement, the Commission shall review the trajectory. 2. The trajectory shall start from the Union's 2030 target for climate […]"*.

Article 4 deals with *"Adaptations to climate change"* and *Article 5* sets 5-year periods for assessing progress achieved, starting by 30 September 2023, mandating the EC to assess existing frameworks and propose or take additional measures, if needed.

Article 6 mandates the EC to regularly assess national measures by *"30 September 2023, and every 5 years, thereafter"*. The EC can issue recommendations but without the right to impose penalties. *"Where the Commission finds […] that a Member State's measures are inconsistent with that objective […], it may issue* *recommendations to that Member State. The Commission shall make such recommendations publicly available"*. The Member State has to take the recommendations into consideration, but *"If the Member State concerned decides not to address a recommendation or a substantial part thereof, that Member State shall provide the Commission its reasoning"*. Public blame and shame are the strongest tools the EC can apply according to the proposal.

In March 2019, the European Parliament endorsed the climate-neutrality target [13], and in November 2019 it underlined that the EU should strive to reach the target *"by 2050 at the latest"*, and it strengthened the call by declaring a climate and environment emergency [14]. The European Council had a more difficult discussion because some Member States were not willing to endorse the greenhouse gas neutrality objective by 2050 and therefore tried to build a blocking minority against the endorsement. It took until 12 December 2019 that the Council endorsed the objective [15].

Based on the *European Climate Law* and as a background for an amendment regarding the 2030 target, the objective of the ***2030 Climate Target Plan*** [16] is to analyze *"the economic, social and environmental impacts"* and *"possible policy measures"*.

Accelerating the development and deployment of energy efficiency and renewable energy is at the heart of the green transformation. Therefore, Member States need a common understanding with the EC regarding which financial incentives could be offered. This is why EC regularly provides guidelines about admissible state aid and thus accelerates clearance for new or modified legislation. In this context, the ***Guidelines on State Aid for environmental protection and Energy 2014–2020*** [17] were an important tool, because they outline what the EC considers admissible state aid. The assessment of necessary adaptions to new legislation, such as the revised *Renewable Energies Directive* [19] or the revised *Energy Efficiency Directive* [20] and other parts of the *Clean Energy for all European Package* [21] began immediately with a series of public consultations, drafts and involvement of the EU Member States and the European Parliament.

Eventually, in February 2022, an adapted version of the guidelines was published [18] with a new title ***Guidelines on State Aid for Climate, environmental protection and Energy 2022.*** It turned out to be a completely revised document with a broad range of detailed definitions and assessments of state aid that could be compatible with EU principles. The assessment covers state aid *"for the reduction and removal of greenhouse gas emissions including through support for renewable energy, for the improvement of the energy and environmental performance of buildings, for clean mobility, for resource efficiency and for supporting the transition towards a circular economy, for the prevention or the reduction of pollution other than from greenhouse gases, for the remediation of contaminated sites, for the rehabilitation of natural habitats and ecosystems and for biodiversity and nature-based solutions",* and for state aid *"in the form of reductions in taxes or parafiscal levies, for the security of electricity supply, for energy infrastructure, for district heating and cooling",* state aid *"in the form of reductions from electricity levies for energy-intensive users, for coal, peat and oil shale closure, for studies or consultancy* *services on environmental protection and energy matters"*. For each of these categories, the rationale for and against admissible state aid is assessed against the scope of the activities which will be supported, the minimization of distortion of competition and trade and the avoidance of undue negative effects.

Stakeholders' first assessment of the new guidelines was mixed but overall positive. The ambition to set up a framework in line with the Green Deal and aiming at extensive deliberations on risks of locking-in fossil and other unsustainable solutions was widely welcomed as well as the critical assessment of transitional technologies and resources in principle. On the negative side, it was criticized that the principle of technology neutrality risks to open various backdoors for unsustainable *"low carbon"* energies, such as nuclear, fossil gas, CCS and hydrogen from unsustainable sources. Among the criticized elements was the insufficient recognition of the importance of energy communities, prosumers and also small and medium-sized enterprises (SME), particularly because auctioning is set as the guiding principle for acceptable state aid, which usually is favoring bigger market players.

But exceptions from auctioning are allowed. Although they are limited and subject to low thresholds, this part of the guidelines is much better now than some stakeholders had suspected. The guidelines allow for support of renewable energy projects without prior auctioning for smaller projects, particularly for electricity generation, storage and consumption projects below or equal to 1 MW capacity, demand or consumption and for heat generation and gas production within the same limits. For 100% SME-owned or renewable energy community projects support without prior auctioning may be granted below 6 MW installed capacity or maximum demand. And for windpower projects only, if they are 100% owned by small and micro enterprises or by renewable energy communities, the threshold is 18 MW.

On 10 March 2020, the EC presented ***A new Industrial Strategy for Europe*** [7] comprising a chapeau document [8], a communication titled ***An SME Strategy for a Sustainable and Digital Europe*** [9] and explanatory factsheets. The ambition is high: *"**We now need a new industrial way for Europe, fit for the ambitions of today and the realities of tomorrow**. At the heart of this is the ability of Europe's industry to lead the twin transitions and drive our competitiveness. It cannot afford to simply adapt – it must now become the accelerator and enabler of change and innovation"*. It lays out *"what we want to achieve by 2030 and beyond"* and this means that *"Europe needs an industry that becomes greener and more digital"*. The proposal highlights a broader approach: *"All industrial value chains, including energy-intensive sectors, will have a key role to play"*. Europe must *"create lead markets in clean technologies"* and not only for a few big players: *"Regulatory policies, public procurement, fair competition and the full involvement of SMEs will be essential to make this happen"*.

The EC underlines that the *"next five years will be decisive to set the right enabling conditions for this transition"*. The communication describes key actions for *"Making it happen"* in a number of policy areas. There is the need for *"certainty for industry. A deeper and more digital single market",* and there is the need for *"Upholding a global level playing field"*, and *"Supporting industry towards climate* *neutrality"*. This comprises the proposal for a new *Just Transition Mechanism* and a *Just Transition Fund* [22] which should *"mobilise €100 billion to ensure a fair transition for carbon-intensive regions as they continue to transform their industries and economies"*.

The EC highlights the need for *"a more strategic approach to renewable energy industries"*. This approach, however, mentions the examples *"offshore energy"*, and *"clean hydrogen"* in the context of a *"new strategy for smart sector integration"*. Other renewable sources are not mentioned. And *"clean hydrogen"* is not limited to **green hydrogen**, which leaves the door open for fossil-based hydrogen. The strategy includes a *"focus on sustainable and smart mobility"*, and the announcement that the EC *"will propose a* ***Carbon Border Adjustment Mechanism*** *in 2021 to reduce the risk of carbon leakage, in full compatibility with WTO rules"*. To generate support for clean technologies in Europe by pricing carbon and other pollutants, much will depend on how this mechanism will be designed – which was still not fully agreed upon and decided when this paper was finalized in mid-June 2022 [23].

The *New Industrial Strategy* is linked to the need of *"leveraging and blending EU money with Member States and other institutional partners, as well as crowding in private investors"*. This shall be achieved by an *InvestEU* and a *Green Deal Investment Plan.* Together with the *European Climate Law* criteria were agreed [24, 25] for sustainable investment in the context of a proposal for a *Regulation on the establishment of a framework to facilitate sustainable investment* **(EU Green Taxonomy)**. Another part of the *European Green Deal* could be a proposal for a revision of the ***Energy Taxation Directive*** [26]. Taxation in the EU, however, requires unanimity among Member States. Therefore, their process is still not finalized because it is difficult to reach a meaningful result, which would accelerate Europe's shift towards climate neutrality.

4 Fit for 55 Package

In July 2021, the EC presented a major package of legislative and regulatory proposals for implementing the Green Deal labelled *"Fit for 55"* [27]. As shown in Fig. 2 it consists of more than a dozen proposals for new or amended Directives and Regulations, ranging from establishing a ***Social Climate Fund*** (SCF) and a **Carbon Border Adjustment Mechanism** (CBAM) via launching a ***REFuelEU Aviation Initiative*** and a ***FuelEU Maritime Initiative*** and revising and broadening the ***Emissions Trading System*** (ETS), developing more ambitious emissions standards for cars and an ***Alternative Fuels Infrastructure Regulation***, developing a forest strategy, and also revising the ***Energy Efficiency Directive*** (EED) and the ***Renewable Energies Directive*** (RED). In the following, I'll focus on the proposed amendments for the RED, which is at the center of interest for accelerating the deployment of renewables in Europe.

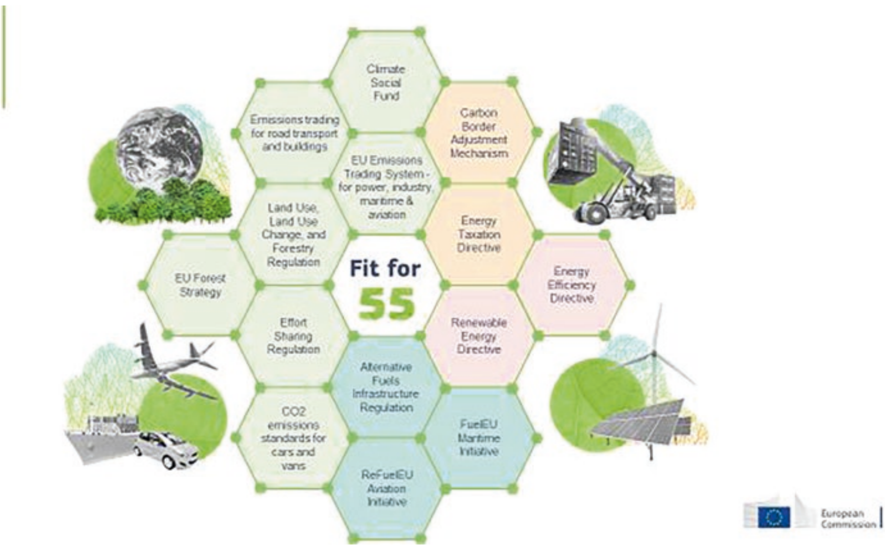

Fig. 2 Building blocks of the Fit for 55 Package. (Source: European Commission [28])

With the revision of the RED [29], the EC proposed to increase the EU's 2030 target from 32% to at least 40% renewable energy in gross final energy consumption. A number of new or higher than before indicative targets were also part of the proposal: 49% renewables in buildings by 2030 and an annual increase of at least 1.2 percentage points for renewables in district heating and cooling networks a 2.2% target for advanced biofuels and 2.6% for renewables of non-biological origin (RFNBO) and others. Power Purchase Agreements (PPA) between renewable energy producers and private and industrial consumers should be incentivized and supported.

In line with the revised ***Energy Performance of Buildings Directive*** (EPBD), which is also in the process of legislation, the switch from fossil to renewable-based heating systems shall be promoted. And respective qualifications and certifications for a growing number of installers shall be facilitated. Member states shall publish lists of qualified installers. Transmission and Distribution System Operators (TSOs and DSOs) shall be required to facilitate the system integration of renewables by making available information about the RE share and the GHG content of the power supply, battery capacity, smart charging capabilities and not to discriminate against small and mobile storage systems. Member states shall be required to develop cross-border renewables projects and to develop a detailed joint offshore energy planning by 2050 with milestones 2030 and 2040. National Energy and Climate Plans (NECP) outlining how Member states will meet their targets shall be due by 30 June 2023, and final versions by 30 June 2024.

The proposed amendments are in the process of consideration and amendments in the European Parliament (EP) and the Council. Stakeholders and some parliamentary groups are pushing for higher targets for the renewables share in 2030 of at least 45%, some are demanding up to 56%. Parliamentarians are asking for more mandatory cross-border projects to increase cooperation and effort sharing. Amendments include detailed rules for simpler and accelerated permitting for new and particularly for repowered installations and to oblige Member States to develop, promote and regularly monitor training and qualification schemes for installers. Among the critical points is the proposed inclusion of non-renewable "low-carbon" hydrogen in the RED and respective quota. An important additional amendment is a request to define renewable energy projects as being in *"overriding public energy and security interest"* in order to further accelerate permitting and help legal assessment in conflicts with other potentially relevant interests.

The EP had originally planned to have at least the vote of the relevant committees before the 2022 summer break and a plenary vote as a basis for the negotiations with the Council by early September. When this paper was finalized these votes had been postponed until after the summer break to accommodate new and more ambitious amendments which became necessary in the context of Russia's invasion of Ukraine and which are part of the ***REPowerEU*** Package [30], which will be presented and analyzed in the next chapter.

5 REPowerEU

On 8 March 2022, the European Commission presented a strategy paper to deal with the repercussions of the Russian war in Ukraine on the EU's energy security and supply diversity titled ***REPowerEU: Joint European Action for more affordable, secure and sustainable energy*** [31]. The document outlined a short and mid-term strategy to accelerate the diversification of energy supply – to a large extent building on accelerating renewable energy deployment. This may well become a game changer for the level of ambition of the EU's quest for a green energy transformation. Driven by and building on the fact that 45.3% of the EU's fossil gas consumption and also high shares of the coal, oil, gas and uranium resources are imported from Russia, the EC proposed a set of measures to mitigate the risks and reduce dependencies at the earliest possible. The proposal includes frontloading of measures of the *Fit for 55 Package* and at the same time increasing some of the ambition levels by suggesting higher targets, removing administrative barriers, developing a solar industry strategy and of course diversification of gas supplies including toward biogas.

Overall, the strategy paper is a call to urgency, in which the *"Commission calls on Member States to ensure that the planning, construction and operation of plants for the production of energy from renewable sources, their connection to the grid and the related grid itself is considered as being in the overriding public interest and in the interest of public safety and qualify for the most favorable procedure available in their planning and permitting procedures"*.

The first list of proposed measures was further detailed and on 18 May the EC presented an updated version of ***REPowerEU*** [31] with a more elaborate ***REPowerEU Plan*** [32] including ten strategy and policy proposals including suggested amendments to the Fit for 55 Package and in particular to the RED including an **increased 2030 renewable energy target of 45%** instead of the 40% in the original Fit for 55 Package.

Among the proposed measures are proposals for diversifying fossil gas supply and gradually replacing it by boosting biomethane production to 35 billion cubic meters (bcm) by 2030. Energy efficiency increase shall replace 38 bcm. Solar rooftop installations shall be frontloaded to producing 15 TWh within 1 year, and ten million new heat pumps shall be installed in the next 5 years. 480 GW of wind and 420 GW of solar capacity shall be installed by 2030. These objectives shall be achieved inter alia by a ***Biomethane Action Plan*** [33] and a revised ***EU Solar Energy Strategy*** [34].

The main elements of the Solar Energy Strategy are the launch ***Solar PV Industry Alliance*** to grow and accelerate domestic production capacities and workforce development and a ***Solar Rooftop Initiative***. A legal obligation to install solar panels shall be created for roofs of more than 250 sqm. As a first step, it shall apply for new public and commercial buildings by 2026 and for all of those roofs by 2027. For new residential buildings the obligation shall be effective as of 2029. In addition, permitting shall be accelerated and simplified so that the maximum duration for permitting for solar rooftop installations shall be 3 months and barriers and obstacles against extending existing installations shall be removed. By 2030, at least 45 GW of new PV capacity shall be installed annually.

Another important element of the ***REPowerEU Plan*** is a document titled ***"Recommendations on permitting procedures and Power Purchase Agreements"*** [35] and related proposals for amendments to the RED [36]. It is suggested to require Member States to establish ***Go-To Areas*** for renewable energy projects to simplify and accelerate permitting procedures. It is proposed that a **single contact point** for all permits must be established. The maximum duration of permitting in go-to-areas shall be 1 year in general or 6 months for installations of up to 150 kW. Outside it should be 2 years in general and 1 year for small installations respectively. Finally, the EC proposes an amendment to define Renewable Energy installations to be of ***overriding public interest.***

As it seems today, the Russian Invasion has triggered a sense of urgency of decision-makers in Europe. The EC's proposals and first reactions from Member States and EP indicate that there is a strong willingness to accelerate the deployment of domestic renewable energy including all elements of the value chain and also to speed up and boost efforts to increase energy import independence.

6 Conclusions and Outlook

Since the IPCC's *Special Report on 1.5 °C Global Warming* [37] underpinned once again the urgency of climate action, the concept of Greenhouse Gas Neutrality within the planetary boundaries is supported by virtually all serious climate scientists and by an increasing number of governments, politicians, stakeholders and civil society organization. Evidence is growing that the remaining carbon budget is too rapidly decreasing. With more extreme weather events and ice caps melting faster than expected, strong efforts to fully implement the Paris Agreement are needed more than ever. It is becoming ever more likely that net zero emissions by 2050 may be too late to avoid the most dangerous impact of the climate crisis, and that the industrialized countries of the Global North have to reduce emissions much more quickly than the developing countries of the Global South. Striving for (net) zero emissions and greenhouse gas neutrality by 2040 the very latest instead of 2050 should become the new target for the EU and other countries of the global north. At the same time, rapidly decreasing costs are making renewable energies the cheapest option for sustainable and secure supply around the world for most end-users. This strengthens the likeliness to reduce greenhouse gas emissions quickly enough to avoid more tipping points to be reached.

The EC's emphasis on the *European Green Deal* and the commitment to Greenhouse Gas Neutrality is widely applauded – with a growing number of scientists and also industry stakeholders advocating for an earlier target year than 2050, and also for a greater than 55% GHG reduction by 2030, such as for example 65%. Now is the time for the EU and Member States (and all others) to increase ambition and implementation and to remove ambiguity from their policies: Accelerate renewables and do not forget to actively phase out subsidies for and the usage of unsustainable energies, fossil and nuclear alike. Financial support from governments needs to be clearly directed to facilitate the uptake of renewables – and not to extend the lifetime of GHG-emitting and hazardous power plants.

The European Parliament and the European Council are in the process of discussing and modifying the EC's proposals for the *Fit-for-55 Package* as well as for the recent *REPowerEU Plan*. Milestones and regular monitoring on the way to (net) zero emissions by 2050 (or earlier if the global responsibility of the industrialized countries is duly accepted) every 5 or at least 10 years will have to be set. Specific targets and milestones for rapidly increasing renewable shares towards 100% and to achieve efficiency gains in all end-uses will be included. The EU should strive for higher ambition, particularly for renewable energy deployment. Instead of 40 or 45% renewables by 2030 a new objective could and should be to achieve 100% renewables for electricity by 2035 at the latest, and for all other end-uses like buildings, industry and transport by 2040. It goes without saying that policies need to be revised and adjusted accordingly.

Binding responsibilities for Member States' fair shares to the Union's energy transformation and penalties in case of non-compliance should be agreed upon and enacted, but it seems that this is unlikely to happen. State Aid rules, support systems, and market designs must be adapted to unleash the full potential of renewables. Administrative and regulatory barriers will have to be removed. Direct and indirect subsidies for unsustainable energy will have to be rapidly phased out to create and ensure a level playing field, where clean, safe, and cheap renewable energy can eventually outcompete dangerous and dirty fossil and nuclear energy sources. And since the Russian invasion is the very latest, it is obvious that import dependence on fossil and nuclear fuels is another critical risk for Europe's (not only energy) security. There is a high likelihood – and a strong necessity – that *REPowerEU* will further accelerate the diversification of resources and deployment of renewable energy.

References

1. Ursula von der Leyen, President of the European Commission, Mission Letter to Frans Timmermans, Brussels, 1 December 2019. https://ec.europa.eu/commission/commissioners/sites/comm-cwt2019/files/commissioner_mission_letters/mission-letter-frans-timmermans-2019_en.pdf
2. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council directive 96/61/EC, OJ L275, 25 October 2003, consolidated version as of 8 April 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02003L0087-20180408&from=EN
3. Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013, OJ L156/26, 19 June 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0842&from=EN
4. European Commission, A Union that strives for more, COM(2020) 37 final, Brussels, 29 January 2020. https://ec.europa.eu/info/sites/info/files/cwp-2020-publication_en.pdf
5. European Commission, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions – The European Green Deal, COM(2019) 640 final, Brussels, 11 December 2019. https://ec.europa.eu/info/publications/communication-european-green-deal_en
6. Transforming our world: the 2030 Agenda for Sustainable Development (Website accessed 04 May 2020, 17:30 CEST). https://sustainabledevelopment.un.org/post2015/transformingourworld
7. European Industrial Strategy (Website accessed 04 May 2020, 18:15 CEST). https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en
8. European Commission, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions – A New Industrial Strategy for Europe, COM(2020) 102 final, Brussels, 10 March 2020. https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf
9. European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – An SME Strategy for a sustainable and digital Europe, COM(2020) 103 final, Brussels, 10 March 2020. https://ec.europa.eu/info/sites/info/files/communication-sme-strategy-march-2020_en.pdf
10. European Climate Pact, Public consultation (Website accessed 05 March 2020, 18:45 CEST). https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12219-European-Climate-Pact
11. European Commission, Proposal for a Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending regulation (EU) 2018/1999 (European Climate Law), COM(2020) 80 final, Brussels, 4 March 2020. https://ec.europa.eu/info/sites/info/files/commission-proposal-regulation-european-climate-law-march-2020_en.pdf
12. European Commission, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions and the European Investment Bank – A Clean Planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final, Brussels, 28 November 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

13. European Parliament resolution of 14 March 2019 on climate change – a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy in accordance with the Paris Agreement (2019/2582(RSP)), 14 March 2019. https://www.europarl.europa.eu/doceo/document/TA-8-2019-0217_EN.pdf
14. European Parliament resolution of 28 November 2019 on the climate and environment emergency (2019/2930(RSP)), 28 November 2019. https://www.europarl.europa.eu/doceo/document/TA-9-2019-0078_EN.pdf
15. European Council, European Council meeting (12 December 2019) – Conclusions, EUCO 29/19, Brussels, 12 December 2019. https://data.consilium.europa.eu/doc/document/ST-29-2019-INIT/en/pdf
16. European Commission, 2030 Climate Target Plan (Website accessed 06 May 2020 17:30 CEST). https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12265-2030-Climate-Target-Plan
17. European Commission, Communication from the Commission, Guidelines on State aid for environmental protection and energy 2014–2020, Official Journal of the European Union 2014/C 200/01, 28 June 2014. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2014:200:FULL&from=EN
18. European Commission, Communication from the Commission, Guidelines on State aid for climate, environmental protection and energy 2022, Official Journal of the European Union 2022/C 80/1, 18 February 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022XC0218(03)&from=EN
19. Directive (EU) 2018/2001 of the European Parliament of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast), Official Journal of the European Union L 328/82, 21 December 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN
20. Directive (EU) 2018/2002 of the European Parliament of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency, Official Journal of the European Union L 328/210, 21 December 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2002&from=EN
21. European Commission, Clean energy for all Europeans package, published 20 October 2017, last update 12 March 2020 (Website accessed 08 May 2020 17:45 h CEST). https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en
22. European Commission, Proposal for a Regulation of the European Parliament and of the Council establishing the Just Transition Fund, COM(2020) 22 final, Brussels, 14 January 2020. https://ec.europa.eu/info/law/better-regulation/ and Annex https://ec.europa.eu/info/law/better-regulation/
23. Proposal for a Regulation of the European Parliament and of the Council on the establishment of a framework to facilitate sustainable investment, COM(2018) 353 final, Brussels, 24 May 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018PC0353&from=EN
24. energypost.eu, Luca Bonaccorsi, Defining green investments, ending greenwash: the EU's new Taxonomy Regulation, 13 February 2020 (Website accessed 6 May 2020 18:30 h CEST). https://energypost.eu/defining-green-investments-ending-greenwash-the-eus-new-taxonomy-regulation/
25. Council of the European Union, Press Release 15 April 2020, Sustainable finance: Council adopts a unified EU classification system (Website accessed 6 May 2020). https://www.consilium.europa.eu/en/press/press-releases/2020/04/15/sustainable-finance-council-adopts-a-unified-eu-classification-system/
26. European Commission, Proposal for a Directive, EU Green Deal – Revision of the Energy Taxation Directive (Website accessed 6 May 2020 18:45 h CEST). https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12227-Revision-of-the-Energy-Tax-Directive
27. European Commission, Delivering the European Green Deal (Website accessed 16 June 2022). https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

28. European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, COM(2021) 550 final, Brussels, 14 July 2021. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550&from=EN
29. European Commission, Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, Brussels, 14 July 2021. https://eur-lex.europa.eu/resource.html?uri=cellar:dbb7eb9c-e575-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF
30. European Commission, REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition (Website accessed 16 June 2022). https://ec.europa.eu/commission/presscorner/detail/de/IP_22_3131
31. European Commission, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. REPowerEU: Joint European Action for more affordable, secure and sustainable energy, COM(2022) 108 final, Strasbourg, 8 March 2022. https://eur-lex.europa.eu/resource.html?uri=cellar:71767319-9f0a-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF
32. European Commission, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. REPowerEU Plan, COM(2022) 230 final, Brussels, 18 May 2022. https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF
33. Commission Staff Working Document accompanying the document Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. REPowerEU Plan, SWD(2022) 230 final, Brussels, 18 May 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2022%3A230%3AFIN&qid=1653033922121
34. European Commission, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Solar Energy Strategy, COM(2022) 221 final, Brussels, 18 May 2022. https://eur-lex.europa.eu/resource.html?uri=cellar:516a902d-d7a0-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF
35. European Commission, Commission Recommendations of 18.5.2022 on speeding up permit-granting procedures for renewable energy projects and facilitating Power Purchase Agreements, C(2022) 3219 final, Brussels, 18 May 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=PI_COM:C(2022)3219&from=EN
36. European Commission, Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, COM(2022) 222 final, Brussels, 18 May 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0222&from=EN
37. IPCC: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (Accessed 10 May 2020). https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf from https://www.ipcc.ch/sr15/

Prospects for Wind Energy in Southern Morocco and Northern Mauritania

H. Nfaoui, A. Abbou, A. Sayigh, and A. Elmalki

1 Introduction

Energy is a strategic factor for economic development. Morocco is still largely dependent on energy imports, more than 90%. To reduce its imported energy dependence, in 2009, Morocco adopted a strategy to increase the share of renewable energies in the installed electrical power to 52% by 2030. Its strategic location allows Morocco to be an electrical hub between Europe and Africa.

Achieving energy security is considered the top priority for Morocco, especially in the current situation characterized by the high price of petroleum products at the global level, and its impact on the national energy bill following the war between Russia and Ukraine.

Renewable energy projects in Morocco are made possible thanks to the establishment of an appropriate legislative, regulatory and institutional framework, which Morocco continues to update, to make the renewable energy sector more attractive to private investment. Morocco has become among the leaders (South Africa and Egypt) of renewable energies in Africa. In 2021, the installed electrical

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power of wind power is 1350 MW, of which 56% (762 MW) is installed in the south of Morocco.

Also, Morocco has developed an integrated water desalination program with power plants backed by renewable energy production units, as well as an ongoing preparation of a marine energy roadmap.

The south of Morocco benefits from an exceptional source of renewable energy and will experience, over the next decade, the development of a large portfolio of wind projects.

The south of Morocco benefits from an exceptional source of renewable energy and will experience, over the next decade, the development of a large portfolio of wind projects. Transporting energy to the consumption centers requires the reinforcement of the 400 kV alternating current network in the south of Morocco and the subsequent increase in the transit capacity of this network, so as to ensure the transit of the production of renewable source projects under development.

The greater increase in electricity consumption in Mauritania has prompted it to take an intensifying interest in the development of the production of electricity through renewable resources. A target of 129 MW has been set for wind technologies by 2030.

Since 1997, the Moroccan electricity network has been connected to the Spanish homologous, and the continental connection with the Mauritanian one will constitute a model of regional integration which will modify the characteristics of Atlantic Africa.

Mauritania shares similar wind resources with southern Morocco, mainly for the North coastal zone. The installed wind power in Mauritania is 34.4 MW. The renewable energy project, including wind power, is a model for the integration of the South of Morocco and North of Mauritania.

2 Statistical Characteristics of Wind Speed

2.1 Mean

We have available N measurements v_i. we define the mean of the quantity v by the ratio:

$$\bar{v} = \frac{1}{N} \sum_{i=1}^{N} v_i \tag{1}$$

2.2 Variance and Standard Deviation

The variance of a series of values of the parameter v_i is the mean of the squares of the deviations of these values from their mean:

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}\left(v_i - \bar{v}\right)^2 \tag{2}$$

The standard deviation (mean squared deviation) is the square root of the variance: σ_v

2.3 Influence of the Period of Measurements on Wind Potential Assessment

For the Tangier site, North-West of Morocco, it has been shown that the minimum period of hourly measurements that can be considered is 9 years with four measurements per day (0 h, 6 h, 12 h, and 18 h) to properly estimate the wind speed (Histograms, frequencies, daily, monthly variations, etc.) [1, 2]. This shows that the characteristics study of the wind speed and the evaluation of the wind potential available at a given site depend on the duration and the step of measurement of the wind speed, thus the variation amplitude of wind speed.

The annual average wind speed is a variable which gives an order of magnitude of the importance of the wind for a given site. For Tan Tan, Laayoune and Dakhla, the annual averages are around 5.12 m/s, (5.90 ± 0.89 m/s) and (7.64 ± 1.15 m/s) respectively [3]. Dakhla is the windiest site in the South of Morocco. Nouadihbou, located in the North-West of Mauritania, is considered to be the windiest site in the country. During a period of 15 years (2000–2014), recorded in tri-hourly form, the average annual long-term wind speed is around 7 m/s [1].

2.3.1 Seasonal Variations

Lagouira site is a more southern coastal area of Morocco, where it overlooks the Atlantic Ocean on a geographical peninsula. It is located 20 km North-West of Nouadhibou (Mauritania), which overlooks the maritime gulf (Cap Blanc) (Table 1).

The Lagouira diagram, Fig. 1, shows the days per month, during which the wind reaches a certain speed. For Lagouira, June is the windiest month, the daily average wind speed is between 7.9 and 10.7 m/s for 27 days and December is the least windy month; it is only 5 days, but 19 days have an average between 5.4 and 7.9 m/s.

For the other four considered Moroccan sites, October is the least windy month, with a monthly average of around 4 m/s for Tarfaya and 6 m/s for Dakhla (Fig. 2a).

Table 1 Annual average of wind speed and available wind potential [3–8]

Sites	Période de mesures	Altitude *H* (m)*	Vitesse (m/s)	Potentiel disponible (W/m^2)	Fréquences (%) pour $V = 0$ m/s (Vent calme)
Tarfaya	22 years, 1983–2005	–	4.6	360	–
Laâyoune	13 years, 1978–1990	10	5.90	204	2
Dakhla	10 years, 1980–1990	15	7.60	462	2
Tan Tan	2 years, 1993–1994	–	5.12	101(122)**	4

Sites	Période de mesures	Altitude *H* (m)	Vitesse (m/s)	Potentiel disponible (W/m^2)
Nouakchott*	1 year, 2016	30	6.96	258
Nouakchott**	5 years, 2001–2005	–	4.49	85
Boulenouar	1 year, 2015–2016	40	8.87	585
Nouadihbou	10 months, 2016–2017	50	9.12	600

(*): Vitesse du vent à l'altitude *H*; (**): $W = 101$ W/m^2 [5], $W = 122$ W/m^2 [7]

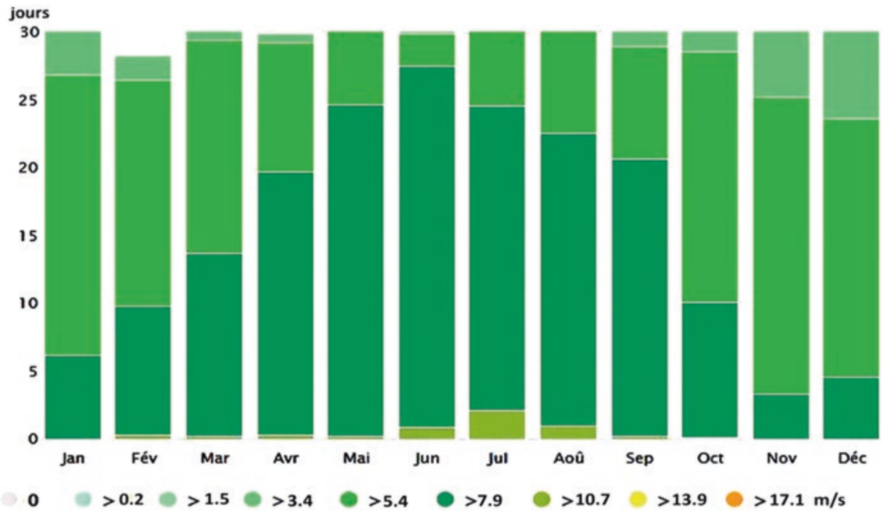

Fig. 1 Monthly distributions of daily averages of wind speed for Lagouira [9]

August and July are the windiest months for Laayoune and Dakhla, respectively, with monthly averages of 7.67 m/s and 10.12 m/s. For Laâyoune, the maximum speed is 34 m/s, in August 1978, while it is 27 m/s for Dakhla, obtained in July 1983 [3].

Nouadhibou and Boulenouar are the windiest sites for Mauritania. For Nouakchott, the gap between the two curves results from the differences between the used measurement periods (1 and 5 years) (Fig. 1).

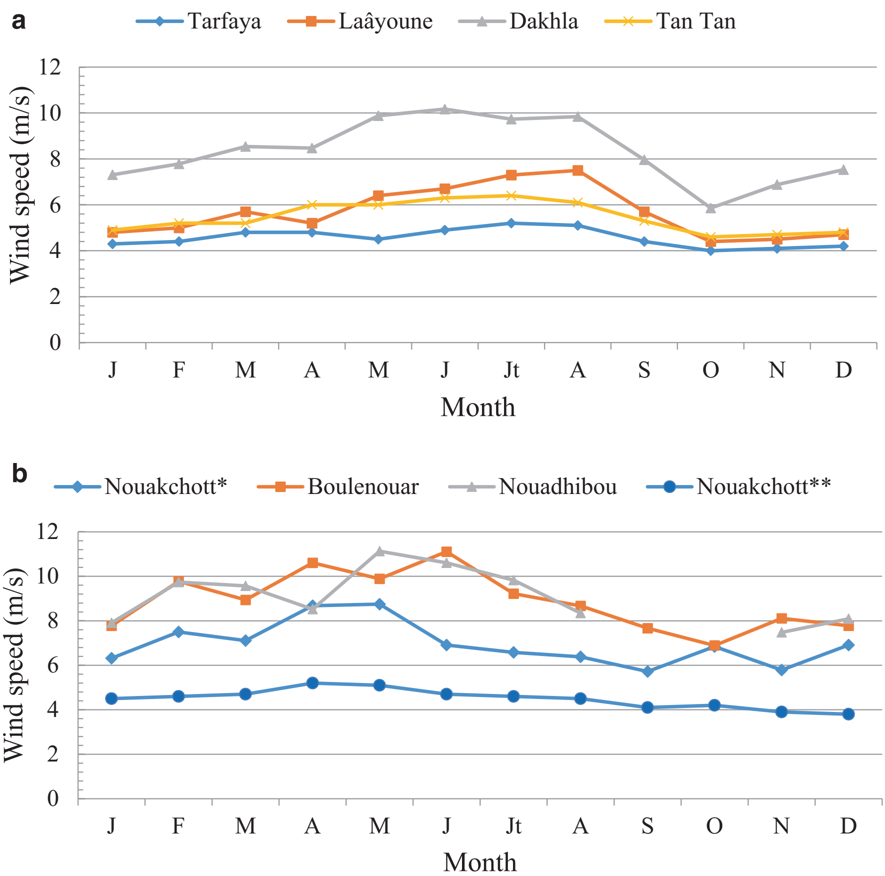

Fig. 2 Monthly wind speed averages [2, 4–7, 10, 11]

2.3.2 Diurnal (Daily) Variations

Figure 3 shows, in general, for the three sites considered that the wind is strong during the day and reaches its maximum around 4 p.m., local time, and weak at night. This phenomenon is mainly explained by the influence of the gradual rise in temperature over the course of the day on the Atlantic coast causing local winds (sea/land breeze) which are added to the winds from the Azores. Knowing this type of variation also makes it possible to harmonize the power recovered from the wind and the energy needs.

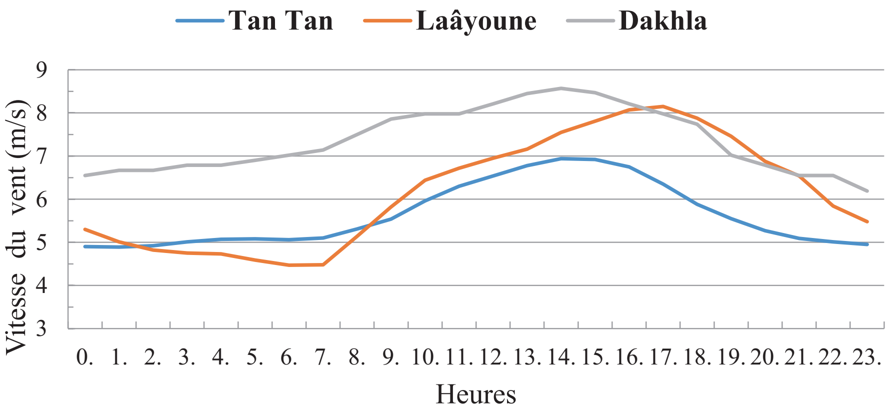

Fig. 3 Daily variations in wind speed [2]

2.3.3 Interannual Variations

Interannual variations, I_i, are another type of temporal variation that correspond to the differences observed from 1 year to another. I_i represents the ith month of the calendar over a period of several years by the formula (3) [6, 12]:

$$I_i = \frac{\sigma_i}{V_i} \tag{3}$$

where:

σ_i: Standard deviation of the monthly means of the ith month,
V_i: Global average speed for the ith month.

This interannual variation factor must be taken into consideration when one wants to ensure that there is a good compromise between the needs and the possibilities offered by a wind system.

Just as the wind varies from season to season, it varies from year to year. This variation, over a period of several years, tells us about the periodicity and irregularities of the wind. At the annual scale, the interannual variation is more important for Dakhla (I_i = 0.2), double, compared to that of Laâyoune (I_i = 0.1) [6]. Thus, the monthly averages for Dakhla vary between 4 and 17 m/s, but for Laâyoune is between 3 and 9 m/s. This confirms that the Dakhla site is the windiest (Fig. 4).

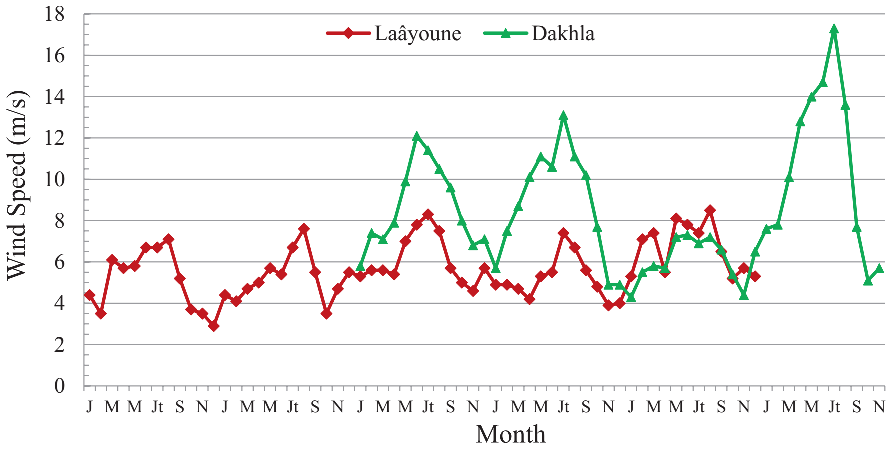

Fig. 4 Variations interannuelles [5]

2.4 Distribution of Wind Frequencies

The histogram represents several hours, for example, for which the hourly wind speed is equal to 0 m/s, 1 m/s, and 2 m/s etc. (on the abscissa). It informs us about the distribution of hours in the different classes.

The annual frequencies for the 0 m/s class corresponding to $V = 0$ m/s (zero wind) are low for the two sites considered (Laâyoune and Dakhla), i.e. approximately 2%. These figures need to be known, for example when it comes to sizing the storage for certain wind energy applications (Fig. 5).

From Fig. 5, we note that the frequencies, for the classes which correspond to wind speeds varying from 5 to 8 m/s, vary between 12% and 14% for Laayoune, or for Dakhla, they are below 12%. But the classes corresponding to high values of wind speed ($V > 10$ m/s) are not empty for Dakhla compared to those of Laâyoune. More than 35% of the time, the hourly average wind speed exceeds 10 m/s, but only 6% for Laâyoune. This confirms that the wind force is the most important for Dakhla.

2.5 Vertical Profile of the Wind Relative to the Ground

The vertical profile of the wind relative to the ground can be used to estimate winds at a different height than an anemometer. The height of wind turbines is usually higher than that of the anemometer in meteorological stations (10 m). Extrapolations are therefore often necessary.

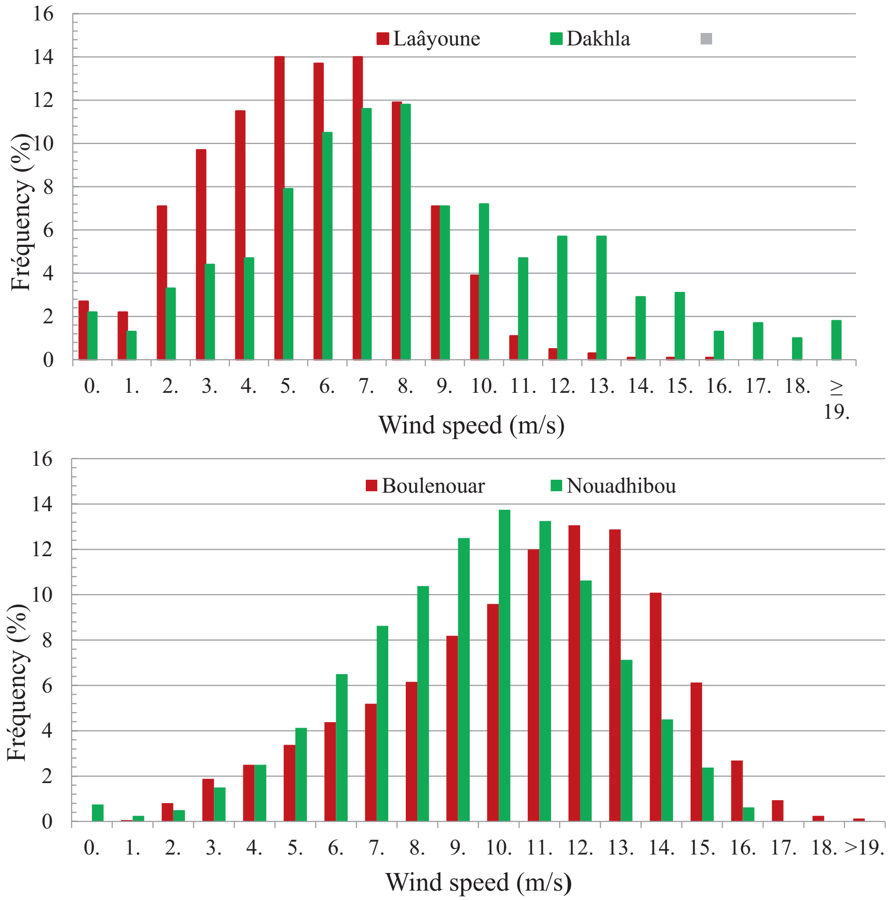

Fig. 5 Histogrammes des mesures horaires de la vitesse du vent [5, 13]

Wind speed increases with height above ground, and this variation can be represented by the following expression [1, 5, 6]:

$$\bar{V}_z = \bar{V}_a \left(\frac{z}{z_a} \right)^{\alpha} \tag{4}$$

where:

$\bar{V}_z$: average wind speed at height z (m),

$\bar{V}_a$: mean wind speed at height (m).

The exponent, α, depends on the average (weather) stability and roughness of the ground surface z_0. The values of z_0 for different types of surfaces are grouped in Table 2.

Table 2 Roughness for various land covers [6, 12]

Surface type	z_o (m)
Marsh, Ice	10^{-5}–$3{\cdot}10^{-5}$
Calm Sea	$2{\cdot}10^{-4}$–$3{\cdot}10^{-4}$
Sand	10^{-4}–10^{-3}
Snowy plain	$4.9{\cdot}10^{-3}$
Grassy area	0.017
Cut grass	10^{-3}–0.01
Short grass, Steppe	0.032
Flat region	0.021
Tall grass	0.039
Wheat	0.045
Beet	0.064
Dwarf palms	0.1–0.3
Shrubs	0.05–0.1
Trees	0.2–0.9
Trees Suburb	1–2
Town	1–4

If long-term wind data are available, the empirical results of Justus [14] make it possible to evaluate the value of α. For a usual range of ground surface roughness, the exponent α is given by the following expression [1, 6]:

$$\alpha = \frac{0.37 - 0.088\ln\left(V_{\mathrm{a}}\right)}{1 - 0.088\ln\left(\dfrac{V_{\mathrm{a}}}{10}\right)} \tag{5}$$

Figure 5 shows that there is a shift in the histograms of Nouadhibou and Boulenouar towards the high values of the wind speed, compared to those of Laâyoune and Dakhla. This may be due to the estimated winds for Nouadhibou and Boulenouar at higher heights (50 m and 40 m) than those for Laayoune and Dakhla (15 m and 10 m). On the other hand, moreover, the short measurement duration for Nouadhibou, only 8 months, based on a single measurement year for Boulenouar is insufficient because it may be the windiest year for this site.

2.6 Wind Roses

The direction of the winds is important for understanding the causes and effects of the wind, evaluating the frequency and the strength with which the wind blows for the predominant directions, as well as for dimensioning the systems using wind energy. The representation most adopted by users is that in the form of an 18-way rose.

The wind rose for Lagouira shows how much per year the wind blows in the direction indicated. The wind is omnipresent in the Atlantic Sahara. It blows most of the time from the North (dominant direction) for Lagouira, on the other hand, from the North-West for Nouadhibou despite the proximity of Lagouira to Nouadhibou (Fig. 6).

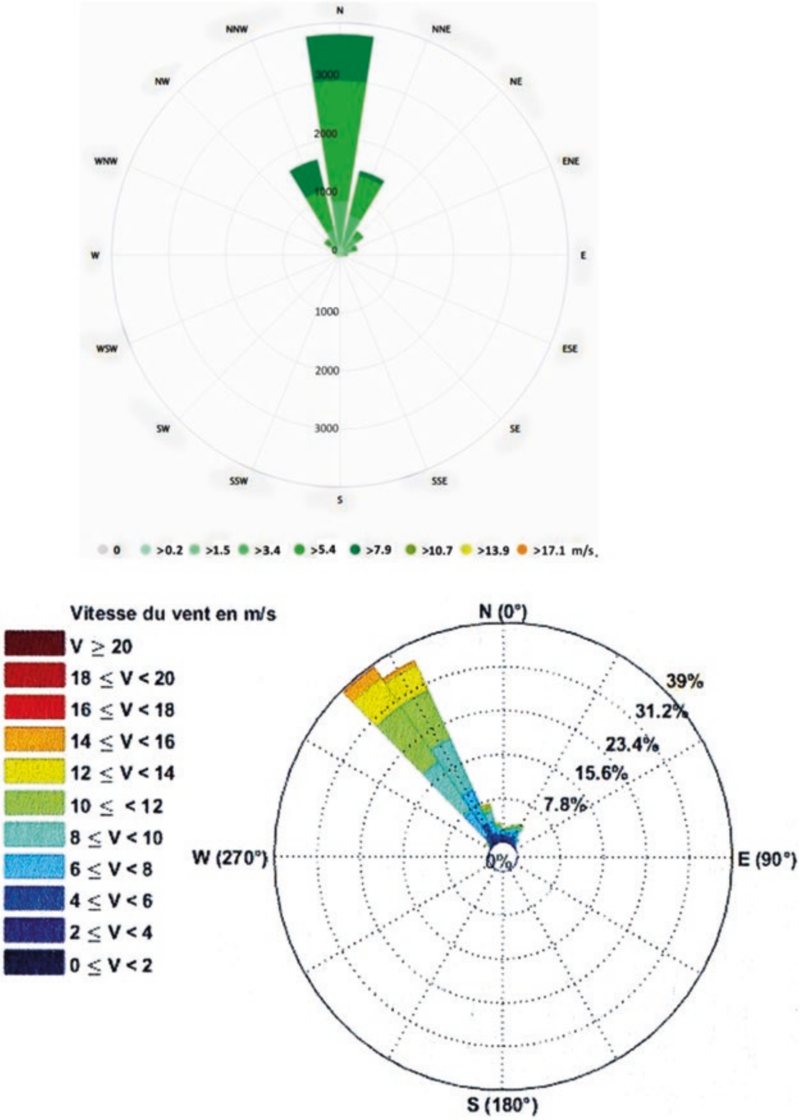

Fig. 6 Wind roses for Lagouira [9] and Nouadhibou [7], respectively

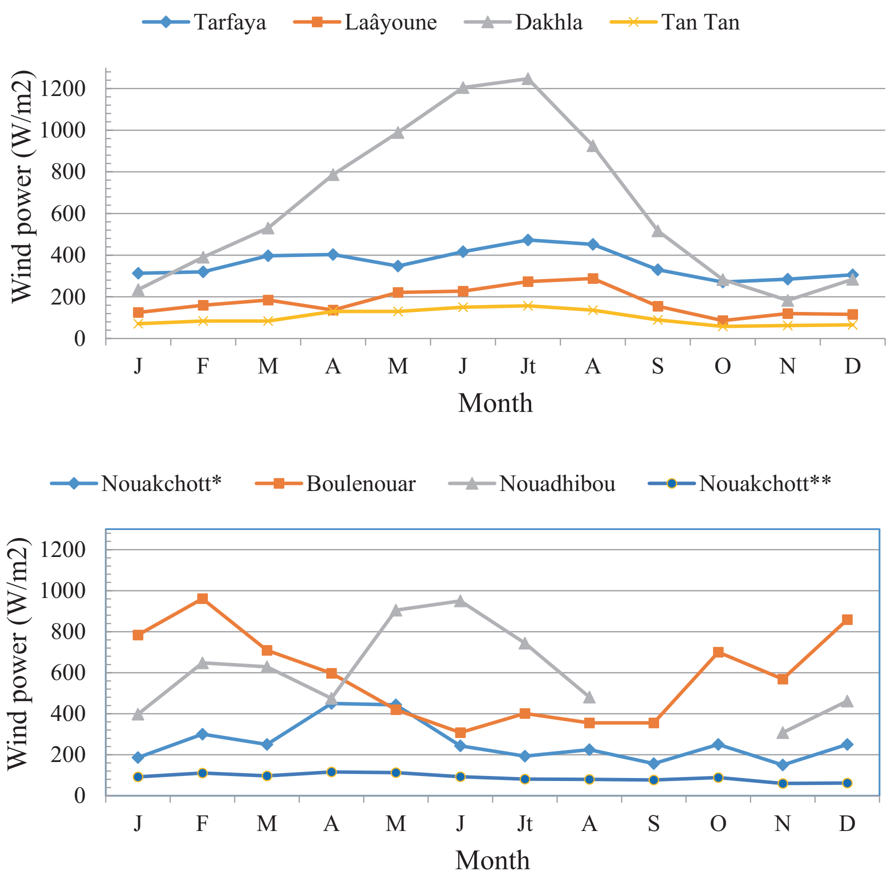

Fig. 7 Monthly averages of available wind power [3–8, 10]

3 Wind Potential Available

It is essential to evaluate the power available in the wind. This characteristic, P (Watts), is associated with a stream of air circulating at speed v (m/s) and acting on a surface S (m^2) by the following formula [1, 6]:

$$P = \frac{1}{2}\rho S V^3 \tag{6}$$

ρ represents the air density (Kg/m^3), which varies with altitude and temperature, but whose value is generally close to 1.2 kg/m^3 [6, 12]. The important aspect of this expression is that the power varies according to the cube of the speed. A 20% increase in wind speed results in a power increase of more than 70%.

The annual averages of the available wind potential, P, are calculated for the sites of Tan Tan, Laâyoune and Dakhla with $\rho = 1.18$ kgm^{-3} [2]. The annual average P for Dakhla is the highest (P = 462 W/m^2), almost double that of Laâyoune and four times that of Tan Tan [3]. Figure 7 shows that the site of Dakhla is the windiest, for Mauritania it is Nouadhibou.

Apart from the Tarfaya site, we note that the pattern of the variations in the monthly average wind speed compared to those of the available wind potentials is similar. For this site, wind speed measurements are taken at a height of 10 m. They are obtained by satellites for 22 years (1983–2005), but the available wind power is estimated at H = 80 m [7] (Figs. 5 and 7)

4 Wind Energy

4.1 Electrical Sectors

As a reminder, the city of Laayoune was connected to the national electricity grid (225 kV) in 1998, which made it possible to connect the province of Smara in 2000, the province of Boujdour in 2003 and the province of Tarfaya in 2008 [4]. But, the city of Dakhla is electrified by a diesel plant (37.5 MW). To cope with the significant increase in electricity consumption in the Dakhla region, a new diesel generator with a capacity of 16.5 MW has been installed by the Electricity National Office (ONE) [15].

The work to connect the city of Dakhla to the national electricity grid was carried out in 2 phases. Firstly, there was the construction of 2 lines 245 km long and 225 kW power each, linking Laayoune-Aftissat. These 2 lines were commissioned in 2018 for the evacuation of the electricity produced by the Aftissat wind farm. As for the 2nd phase, it relates to the realization of 2 lines of length 254 km and 225 kW power each, connecting Aftissat-Dakhla. In 2021, ONE finalized the tests for connecting the city of Dakhla to the national electricity grid [15].

In addition to the reinforcement or development of the transport network in the south of Morocco by alternating current (AC) links, another equally structuring project concerns the reinforcement of the network in the South by the construction of a direct current link (HVDC, 525 kV) [15]. This new achievement will contribute to the development of the southern provinces as well as to the strengthening of their influence as an economic center and as a link between Morocco and its African extension.

4.2 Wind Electricity

In 2021, the wind power installed in Morocco amounts to 1350 MW, of which more than 56% (757.3 MW) is located in southern Morocco [4]. The Tarfaya wind farm 301.3 MW) is the largest wind farm in Africa, installed in 2014. The installed wind

Table 3 Wind farms built-in operation [3, 7, 8, 11, 13, 15–18]

Sites	N° turbines (Nominal power)	Capacity (MW)	Commissioning	Annual production (GWh/year)	Funding	Operator/ owner
Laâyoune	–	5	2011	16	Ciments du Maroc	Ciments du Maroc
Akhfenir 1 (Tan Tan)	61 (1.67 MW)	101.87	2013	330	Nareva Holding	Nareva Holding
Foum ElOued (Laâyoune)	22 (2.3 MW)	50.6	2013	220	NAREVA	EEM*/ NAREVA
Akhfenir 2 (Tan Tan)	56 (1.79 MW)	100.23	2016	405	NAREVA	EEM/ NAREVA
Tarfaya	131 (2.3 MW)	**301.3**	2014	1100	ENGIE ex.GDF Suez/ NAREVA	Tarfaya Energy Company
Aftissat (Boujdour)	56 (3.6 MW)	201.6	2018	1000	NAREVA	EEM/ NAREVA
Total	**–**	**757.3**	**–**	**–**		

(*): société Energie Eolienne du Maroc

Sites	N° turbines	Capacity (MW)	Commissioning	Funding	Operator/ owner
Nouadhibou	16	4.4	2013	–	SNIM*
Nouakchott	15	30	2015	Gouvernement de la Mauritanie	Elecnor SA**
Total	**–**	**34.4**	**–**		

(*): National Industrial and Mining Company; (**): Engineering and construction Spanish company

power in Mauritania is 34.4 MW. The first 4.4 MW park (16 wind turbines, 275KW) was installed by the National Industrial Mining Company in Nouakchott in 2011 (Table 3).

5 Wind Energy Prospects

5.1 Wind Farms Under Construction or Development

The increase in the share of renewable energies, in particular wind power, in Moroccan electricity production will contribute to the reduction of imports of coal and petroleum products, the two most polluting energy products. On the other hand, Wind energy production will contribute to Moroccan energy independence, reduce the purchase of fossil fuels, and consequently the saving of foreign currencies.

Table 4 Wind farms under construction or development [1–4, 12, 15–18]

Sites	Capacity (MW)	Wind speed (m/s) at 10 m	Funding	Operator/owner
Tiskrad (Laâyoune)	100	8.45	NAREVA	NAREVA
Aftissat (Boujdour)	300	–	NAREVA	NAREVA
Total	**400**			

Site	Capacity (MW)	Funding	Operator/owner
Nouadhibou	100	AFESD*	Elecnor**
Total	**100**		

(*): Arab Fund fo Economic & Social Development; (**): Energéticien espagnol Elecnor

As part of Morocco's stated objective of achieving 14% of its installed electrical power from wind power by 2030, other wind farms with a total capacity of 400 MW are under construction or development for the production of electricity in southern Morocco (Table 4). The sites concerned were selected in different windy regions, to ensure better production and stability of the national electricity grid.

In the North of Mauritania, the Spanish energy company Elecnor has obtained the development contract for the third wind power plant (100 MW) in Nouadhibou [17].

In addition, the use of wind energy contributes to the protection of the environment by reducing CO_2 emissions, due to the use of petroleum products and coal, which limits Climate Change such as floods and droughts.

5.2 *Regional Electrical Grid*

The European electricity network is the largest interconnected network in the world in terms of power transported. Since 1997, the Moroccan electricity network has been the only African network connected to that of Europe. Morocco plans to be a regional hub for exporting clean electricity to its neighbors Spain and Algeria (Fig. 8). In addition to the electrical connection project through Boulenouar (Mauritania) and Guergarate (Morocco), in 2018, Morocco and Portugal agreed on the construction of an undersea electrical cable linking the two countries with a capacity of 1000 MW. Thus, technical and economic feasibility studies are carried out in the field. In 2019, Spain and Morocco decided to increase the capacity of electrical energy exchanged between them [11].

In addition to this, the North of Mauritania shares with the South of Morocco similar wind resources mainly for the coastal zone. It is, therefore, possible to have interesting social and economic development in this region once the electrical interconnection between Guerguarate (Morocco) and Boulenouar (Mauritania) is completed.

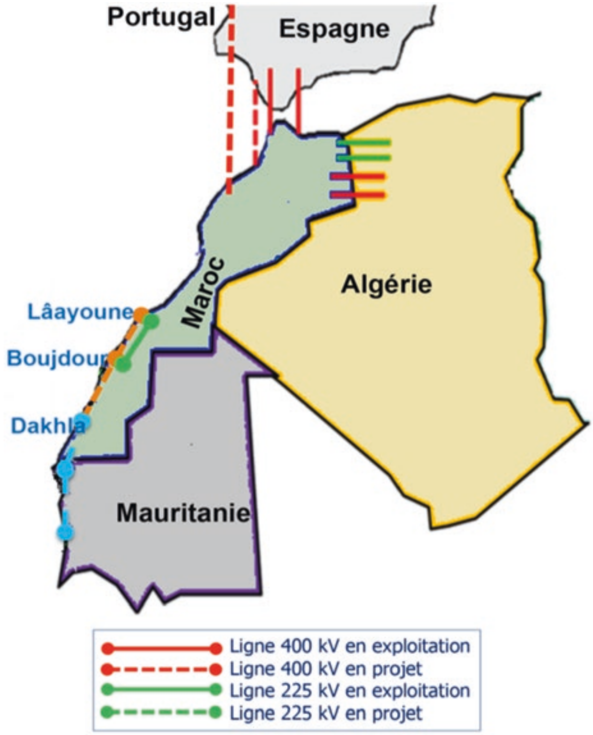

Fig. 8 Interconnexion électrique [11]

6 Conclusion

The study of the characteristics of the wind speed and the evaluation of the wind potential available at a given site depends on the duration and the step of measurement, thus the amplitude and the nature of the variation of the wind speed. For example, for the site of Tangier, North-West of Morocco, it has been shown that the minimum period of hourly measurements that can be considered is 9 years with four measurements per day (0 h, 6 h, 12 h, and 18 h) in order to properly estimate the wind speed (Histograms, frequencies, daily, monthly variations, etc.).

The North of Mauritania shares with the South of Morocco similar wind resources mainly for the coastal zone.

August and July are the windiest months for Laayoune and Dakhla, respectively, with monthly averages of 7.67 m/s and 10.12 m/s. For Laâyoune, the maximum speed is 34 m/s, while it is 27 m/s for Dakhla. The variation in wind speed is more regular for the Dakhla site. For Lagouira, June is the windiest month, the daily average wind speed is between 7.9 and 10.7 m/s for 27 days. On the other hand, for December, the least windy month is only 5 days, so 19 days have an average between 5.4 and 7.9 m/s.

For most of the sites considered, the wind is strong during the day and reaches its maximum around 4 p.m., local time, and weak at night. This phenomenon is mainly explained by the influence of the gradual rise in temperature over the course of the day on the Atlantic coast causing local winds (sea/land breeze) which are added to the winds from the Azores.

The available wind potential is greater for the sites of Dakhla in southern Morocco and Nouadhibou in northern Mauritania where a 100 MW wind farm has been planned to be installed. For Dakhla, at an altitude of 10 m, the annual average of available wind potential is the highest (P = 462 W/m^2), almost double that of Laâyoune and four times that of Tan Tan.

In 2021, the wind power installed in Morocco amounts to 1350 MW, of which more than 60% (757.3 MW) is located in the south of Morocco. The Tarfaya wind farm 301.3 MW) is the largest wind farm in Morocco and Africa, installed in 2014. The installed wind power in Mauritania is 34.4 MW. The first 4.4 MW park was installed in Nouakchott in 2011.

From the perspective of the South of Morocco and the North of Mauritania, wind energy is an alternative and competitive source of energy to petroleum products for the generation of electricity.

The renewable energy project, including wind power, is a model for the integration of southern Morocco with northern Mauritania. In the end, the development of wind energy has important economic and social implications for southern Morocco and northern Mauritania, in the context of advanced regionalization, to take on the role of a real development pole.

References

1. Nfaoui, H. (2004). *Caractéristiques du gisement éolien marocain et optimisation d'un système aérogénérateur/groupe électrogène pour l'électrification des villages isolés* (Thèse de Doctorat d'Etat). Faculté des Sciences de Rabat.
2. Nfaoui, H., & Sayigh, A. (2017). Influence of the period of measurements on wind potential assessment for a given site. In A. Sayigh (Ed.), *Renewable energy and a cleaner environment, innovative renewable energy* (pp. 311–325). Springer.
3. Nfaoui, H., & Sayigh, A. A. M. (2015). Evaluation of renewable energy in the south of Morocco and perspectives. In *Proceedings of Med Green Forum*. Florence, Italy.
4. Enzili, M. (2008). *Renewable energy, energy efficiency in Morocco, situation and prospects*. Cairo (Egypt). www.needs-project.org/
5. Hbib, M. M. A. (2019). *Evaluation du gisement éolien du littoral Mauritanien et analyse des facteurs d'impact sur le système de production d'énergie électrique à base de machine asynchrone à double alimentation, Ecole Mohammadia d'Ingénieurs*. Université Mohammed V de Rabat, Maroc.
6. Knidiri, F., & Laaouina, A. (1986). *L'énergie éolienne au Maroc*. CDER.
7. Bilal, B. O., Kébé, C. M. F., Sambou, V., Ndongo, M., & Ndiaye, P. A. (2008). Etude et modélisation du potentiel éolien du site de Nouakchott. *Journal des Science pour l'Ingénieur*, (9/2008), 28–34.
8. Tizgui, I., Bouzahir, H., El Guezar, F., & Benaid, B. (2016). *Estimation of electricity production for a Moroccan wind farm*. https://www.researchgate.net/publication/342000267

9. https://www.meteoblue.com/fr/meteo/historyclimate/climatemodelled/lagouira_maroc_6546558
10. Enzili, M., Nayssa, A., & Affani, F. (1995). *Le gisement éolien marocain*. le Centre Développement des Energies Renouvelables.
11. Nfaoui, H. (2020). New horizons for renewable energies in Morocco and Africa. In *Renewable energy and sustainable buildings* (pp. 551–565). https://link.springer.com/chapter/10.1007/978-3-030-18488-9_44
12. Mohamed, S. A., Beyoud, A., Ethmane Kane, C. S., Zejli, D., & et Sid Ahmed, M. O. (2017). Etude des données du vent et évaluation du potentiel éolien à Nouadhibou (Mauritanie). *Revue des Energies Renouvelables, 20*(3), 511–520.
13. Nfaoui, H., & Sayigh, A. A. M. (2014). Contribution of renewable energy to energy independence in Morocco: Wind energy case. In *Proceedings of World Renewable Energy Congress 2014*. London, UK.
14. Justus, C. G. (1980). *Vent et performances des éoliennes*. SCM.
15. Finances News HEBDO (Hors Série), Hebdomadaire de l'Information Financière, N° 41, Juillet 2021.
16. https://www.nareva.ma/fr
17. https://www.thewindpower.net, https://éolienne.f4jr.org/parcs/star
18. Nfaoui, H. (2020). Wind energy in Morocco: Resources, potential, and progress. In *The age of wind energy* (pp. 219–282). https://www.springer.com/gp/book/9783030264451

Co-design Inclusive Relations Between Humans and Environments Adopting a Citizen Science Approach

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1 Introduction

The correlation between human activities and climate change is becoming increasingly evident due to the recurrence of extreme climate phenomena. The COVID-19 pandemic is just one of the last "wake-up" alerts for urgently rethinking behaviors that have been forced to change during lockdown providing further evidence of human impacts on the environment (i.e. pollution reduction, re-naturalization, rewilding, relation to human health-environment conditions, etc.). In addition to the pandemic period and climate change, emergencies generated by ongoing conflicts are influencing the increasing global competition for energy and resources disproportionately impacting the poorest and most vulnerable populations.

This happens in European territories, where inequalities are intensifying due to a number of demographic and economic phenomena, notably ageing (with many elderly people being less able to cope with environmental impacts), increasing ethnic diversity and rising numbers of people experiencing poverty and/or social exclusion, with the outcome to produce different configurations of environmental vulnerability, especially in the city contexts [1]. The role of cities in combating climate change is widely recognized as a crucible of innovation [2] (to catalyze

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insurgent strategies promoting reductions in greenhouse gas emissions, testing coping mechanisms, such as disaster warning systems and mutual self-help networks, and improving social and economic equity, ultimately reducing vulnerability to climate change impacts through mitigation and adaptation measures and sustainable urban regeneration) on the development of local adaptation strategies to respond to actual climate impacts and reduce existing vulnerabilities of the territory. In this general framework, the design and management of open and public spaces can play a key role by reducing soil permeability, enhancing water management, improving air quality, and contributing to the psycho-physical health of people. These new values are at the basis of new collaborative initiatives, in which communities can be agents to achieve the transition of urban spaces in low-carbon and resilient realms.

From an institutional perspective, with regard to the European context, the importance of intervening in cities to contrast climate change and environmental extreme phenomena is often aligned with the necessity of involving citizens, both stakeholders and users, in transition processes. EU plans – e.g. the European Green Deal – define the need to introduce new jobs and education patterns related to[1] the ecological transition and initiatives such as the 100 Climate Neutral Cities by 2030, emphasizing[2] the need to engage inhabitants in co-defining actions and frameworks.

2 Co-design of Ecosystem Services

Collaborative design practices are already used by the actors of the Quadruple Helix Model [3] to improve and activate new products and services and tools within their territories:

- PAs and institutions work with participatory planning sessions, involving communities and citizens to improve their services, making them actors of the change (community's empowerment)
- Communities conduct civic activism initiatives aiming to improve the relationship with the urban context, adopting co-design as a mechanism for the democratization of society and knowledge
- Companies adopt design thinking at the management level to hypothesize new business scenarios
- Academic & research participate in co-design processes by creating research practices to mix and match different forms of knowledge (explicit, tacit, direct experiences, etc.)

Starting from these different approaches and practices, the research lines conducted in Bologna intend to deconstruct this verticality, prototyping a methodology

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

[2] https://ec.europa.eu/info/publications/100-climate-neutral-cities-2030-and-citizens_en

of work and a related set of practices, to adopt horizontally co-design human-environments relations for urban green ecosystem services. This will be achieved through intense and iterative experimentation on the ground, geared towards the emergence of a network of needs and opportunities, capable of boosting awareness raising and a shift towards sustainable behavioral patterns, according to a systemic methodology to manage, deliver and visualize monitoring and piloting activities. This overall objective breaks down into three specific goals:

- Developing a data-driven research and innovation approach involving stakeholders in the co-design of humans-environments relations
- Significantly advancing the knowledge and evidence base of ecosystem services as elements of climate mitigation, but also as socio-economic tipping points
- Enhancing innovation capacity and integration of this new knowledge by maximizing the use of innovative communication approaches, including direct elicitation of end-user needs

With regard to the case of Bologna, the research action on the reconnection between humans and the environment, favoring the construction of new assemblages with natural elements, is oriented on the enhancement of ecosystem services' acknowledgement and production in the urban context.

Ecosystem services (ES) are defined as the various and diversified benefits to humans that are produced by the natural environment [4]. Well-designed green areas create the potential for ES production. Human behavior and institutional arrangements modify the ecosystem and, in doing so, affect the actual ES production and provision [5]. A framework is needed to operationalize human behavior/ES production interaction. Considering that ecosystem services' production is related to the existence and maintenance of natural elements in the urban context, actions related to their enhancement should be oriented also toward promoting collective and individual behaviors able to respect, or even improve, natural elements in cities. In this paper will be presented two projects applied in the city of Bologna, Italy, that are oriented on improving green infrastructure and ES both from a strategic perspective, as in the case of the Impronta Verde vision, and from an operational and citizen-led perspective, as in the case of the ReSET[3] project's application in Bologna.

3 Visions and Experimental Activities in the City of Bologna

Impronta verde (Green Handprint) is one of the current flagship projects of the Municipality of Bologna.

The Impronta verde project was launched during the Mayor's election campaign, and in its first representation it was depicted by a "green hand" graphic which overlapped the map of the Municipality of Bologna (Fig. 1). The green hand palm and

[3] https://cordis.europa.eu/project/id/101017857

Fig. 1 Impronta verde first schematic representation. (Image by Municipality of Bologna and Fondazione Innovazione Urbana)

its five fingers correspond to six urban parks: from West to East each finger corresponds respectively to: Città-Campagna Park, Reno Park, Navile Park, Arboreto Park and Savena Park, while the green hand palm corresponds to the hills included within the city borders (Collina Park).

Figure 1, even if it is schematic, is able to clarify the means of the strategic project and to orient the actions of the City Council and Municipality Offices, which are now progressively elaborating a more precise definition of the projects aimed at its actuation.

A threefold perspective emerged from the schematic representation:

– Impronta verde's approach considers the municipal territory by highlighting its empty spaces instead of its built environment (which is more related to traditional urban planning) and delineating a sort of "reverse city" [6] vision of Bologna. This kind of vision connects and valorizes the urban open spaces, whose role appears fundamental also with regard to the pandemic period [7], as places for human well-being and social life. Impronta verde project is characterized by the absence of borders, highlighting the importance of seeking inclusive, functional, ecological and landscape-related relationships on a Metropolitan scale, considering also the other municipalities around Bologna. Those relations are also part of planning tools and projects that have been produced during the previous City Council mandate (2016–2021) such as the PUMS (Bologna's Plan for Sustainable Mobility),[4] the PTM (Bologna's Metropolitan Territorial Plan)[5] and the PUG[6] (General Urban Plan of Bologna).[6] The language: the definition of "Parks" with regard to extended green areas that in part already exists on the municipal territory, appears innovative because it tends to highlight a change of function of those areas, which suggest that expansive park networks are linked to multiple aspects of health and well-being in cities and positively impact the urban quality of life. Impronta verde project has to be considered not as a sum of single green areas and gardens, but as an ecological infrastructure, able to connect humans and the environment, composed of extended territorial parks, each one characterized by specific identity and provided of a tailored plan for the actuation and management. The aim of the current City Council mandate is to define the Impronta verde project more in order to start with its actuation. The temporal perspective for the completion of the project is about 10 years and a strong integration with all the current and future public policies that are and will be implemented by the Municipality is needed. This integration between different public policies is an objective which is not only related to the Impronta verde project but also to the actions required for the EU's mission of 100 Climate-neutral cities by 2030,[7] in which Bologna has been[7] selected at the beginning of 2022. The municipality is currently committed to strengthening the connection between the Impronta verde vision with other plans and projects already active in the city, such as the design of the new tram lines, the urban and metropolitan bike lanes, the network of hillside paths, the programme for new green school squares, the redevelopment of public buildings (cultural spaces, libraries and community centers with nzeb features), with the aim of defining a comprehensive project that acts as a "Landscape Palimpsest" [8] able to orient both the definition and the narration of the public space, by overlapping different thematic layers. These layers are assumed as strategic pillars by the public administration to operationalize the vision and to identify the expected impacts of the connected actions on the human-environment domain.

- *The Biodiverse city* which guarantees continuity to ecological corridors to protect urban wildlife
- *The 30 km/h city* which integrates a vision of public mobility system to make public roads more inclusive and secure
- The 5 minutes city in which reaching green areas is easy and accessible to all thanks to sustainable public transport system
- *The Collaborative city* in which the management of six parks and of public space, in general, is shared between citizens and the municipality
- *The Good city*, thanks to a human-oriented landscape project that gives precise identity to the city and valorizes the specificity of each part of the territory

[4] https://pumsbologna.it/

[5] https://www.ptmbologna.it/

[6] http://dru.iperbole.bologna.it/piano-urbanistico-generale

[7] https://ec.europa.eu/info/publications/100-climate-neutral-cities-2030-and-citizens_en

The identification of these pillars has a strong connection with the activation and completion of other urban projects, both major infrastructure interventions, funded by the PNRR (National Recovery and[8] Resilience Plan) such as railways improvement, the electrification of the whole public mobility system, the regeneration of the local part of the highway and minor but important projects such as the design of tactical urbanism initiatives for new public education areas or interventions on road security for bikers and pedestrians. All the mentioned projects are to be considered as bricks to build a comprehensive Impronta verde vision and are aimed at experimenting with methods and practices useful to better define a dedicated economic plan that will be produced before the end of 2022 and will include funding by the PON Metro national programme.[9] In this work, characterized by punctual implementations and the development of an overall framework, an important role is attributed to the dimension of public confrontation and collaboration. The Impronta verde human-oriented landscape project will be accompanied and built together with citizens, through six tables dedicated to the co-design and shared management plans for the six identified territorial parks. This approach reflects and synthesizes the experiences already carried out in the city's districts during the previous City Council mandate, in close cooperation with the Foundation for Urban Innovation [9], and benefits from the tools and working methods already developed and tested with the University support (such as ROCK project) and for example through the Participatory Balance or during the public discussion phases for the formation of the General Urban Plan.

In this general framework, a new opportunity for experimentation and integration emerged, thanks to a collaboration between the Advanced Design Unit of Bologna and CNR, signed under the umbrella of ReSET (Restarting the Economy in Support of the Environment through Technology) project. It is an EC H2020 project funded under European Union's Horizon 2020 FET Proactive Programme for the period 2021–2023. The main objective of ReSET is to apply environmental intelligence to seek investments able to maximize environmental and economic benefits for territories. The project brings together human and machine intelligence by hybridizing environmental data obtained from ground-based weather stations, satellite and citizens' monitoring, investigated through analytical technology and machine learning to understand and manage local investments [10]. ReSET is working on seven demonstration sites in Europe (Thames Getaway and OxCam Arc – UK, Carasuhat Wetlands – RO, Castilla León and Rivas VaciaMadrid – ES, Bologna – IT) in which investments for reducing extreme climate phenomena are already active. With regard to the case of Bologna, the main research focus is to co-design green interventions for reducing thermal extremes. The case study aims at interconnecting the city center of the municipal area, which has a high density of buildings and a scarce percentage of vegetation, and suburban areas which generally

[8] https://www.mise.gov.it/index.php/it/pnrr

[9] http://www.ponmetro.it/

present a lower density of buildings, wider roads and a variable amount of vegetation, which tends to become higher by getting further from the city center. According to a study on urban microclimate carried out using data on surface temperature and morphological characteristics of the territory from 2017, a large increase in air temperature corresponds to low values of the percentage of vegetation [11]. The study was made in the frame of the definition of the General Urban Plan (PUG) of Bologna and provides a static photograph of microclimate classification during an average summer day. The aim of ReSET study in Bologna is to carry out continuous monitoring of microclimate-related factors to be integrated into an environmental model in order to co-design possible interventions to reduce climate extremes impacts on citizens well-being and improve ecosystem services production. Data will be collected in the period 2022–2023. To this aim, data collected through Freestation – i.e. low-cost weather stations installed in different areas of the city – will be combined with crowdsourced data, collected by activating a citizen science initiative. Data-gathering and data visualization will be carried out simultaneously to provide immediate and comprehensible feedback on the progress and results of the monitoring, which will integrate both quantitative and qualitative aspects and citizens' perceptions. The definition of the experimental area was defined along with the Municipality to make the experimentation also useful for Impronta verde actuation. ReSET will work on an area located on the West part of Bologna (Fig. 2), which includes the following landscape typologies:

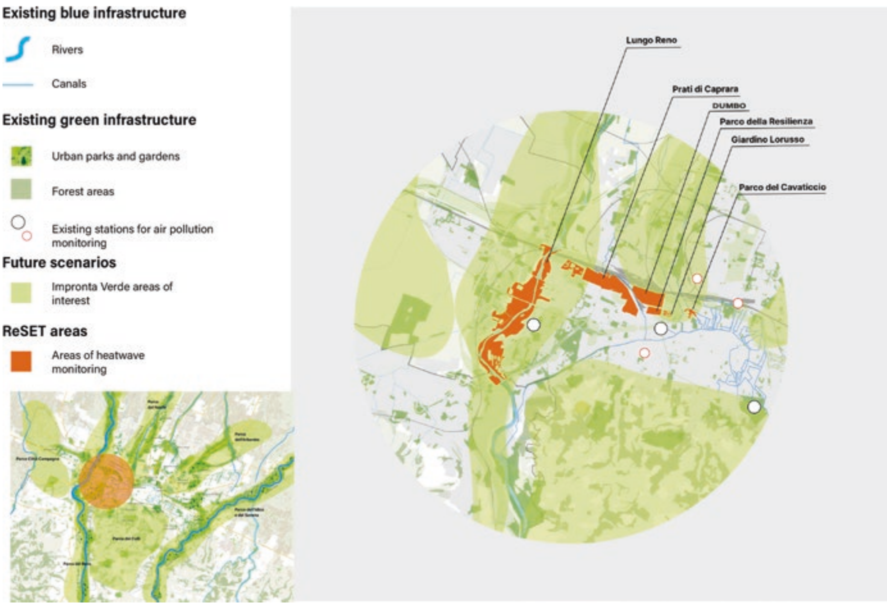

Fig. 2 ReSET area in Bologna

– City center area with a high density of gray infrastructure and scarce percentage of vegetation
– Big open-air areas
– Areas with buildings further from the city center with a higher percentage of vegetation;

For each landscape typology, 2 sub-locations have been selected, one characterized by a higher percentage of vegetation, and one characterized by a higher percentage of buildings, in order to investigate how and under which conditions green infrastructure and ecosystem services are able to mitigate climate extremes. In the selected areas will be activated both ground-based monitoring and crowdsourced monitoring. With regard to ground-based monitoring, in each sub-location will be installed Freestation weather[10] stations before the end of 2022. Freestation initiative provides low-cost hardware and open-source software for environmental monitoring. The typologies of weather stations chosen for the demonstration case of Bologna measure air temperature, humidity, solar radiation, wind speed and direction. Collected data will be open source and available through the Freestation platform. With regard to crowdsourced monitoring, this will be activated along with a citizen science process aimed both at collecting data and at communicating the research process and findings. In fact, according to ECSA's (European Citizen Science Association), a project based on citizen science should involve citizens in research projects to generate new and reliable scientific knowledge, but should also be inclusive and give benefits to citizens that participate in it [12]. The ReSET citizen science process is based on the use of user-friendly platforms for collecting diffused environmental data and qualitative data on citizens' perception of the existing green areas' effectiveness in producing the expected ES (Fig. 3), in order to define a database useful both for environmental monitoring and for green interventions co-design. Communication of the intermediate results will be shared through data visualizations designed for different levels of data interpretation skills. The citizen science initiative will be activated by involving local associations in ReSET areas of interest that will play the role of activators and nodes to involve local inhabitants and citizens. The expected results of ReSET actions in Bologna are:

– The collection of environmental data related to microclimate and thermal extremes and the production of environmental model related to the urban context;
– The gathering of qualitative data from citizens in relation also to perceptual factors in the selected areas – Co-design of proposals for green interventions based on the combination of qualitative and quantitative data and through working tables between citizens, associations and technicians.
– Capacitation of citizens with regard to environmental and thermal extremes related phenomena through communication based on tailored data visualization elaborations.

[10] http://www.freestation.org/

Fig. 3 Test of data crowdsourcing experience with students of the Advanced Design Masters Degree – University of Bologna

4 Conclusions and Openness

Impronta verde and ReSET actions, although working at different scales, present a similar approach: each project recognizes the importance of participation and of citizens' capacitation and involvement with regard to different aspects of the climate crisis, in particular in the urban context in which climate change impacts are affecting human well-being. Both of the presented case studies take as an assumption the fact that reducing the distance between institutions (Municipality and Academia) and inhabitants of the city could lead to the definition of plans, interventions and solutions that are mutually shared and more effective in contrasting climate change impacts. The activation of feedback loops through visualization tools, to support activate cognitive, competence-based and procedural changes, also with relation to gender and diversity issues, in:

- Research institutions that could benefit the application and the testing of extended and balanced citizen science methods about just and green transition processes
- Civil Society, more aware and empowered about a just and green transition processes
- Governmental institutions in orienting policies to people's needs related to EU Green Deal

In order to achieve that, particular attention has to be given to the development and use of citizens-friendly platforms, spaces and occasions for knowledge sharing, also by taking into account the specificities and intrinsic diversity that characterize the civic society. Existing open data platforms and data repositories are usually developed, managed and provided by technicians. It can be challenging for citizens to access and use them, especially to get a full understanding of provided data. Institutional monitoring systems, therefore, are seen as big containers of cryptic data not easily linkable with people's needs or environmental issues. Furthermore, since the achievement of SDGs is highly dependent on their effective interdisciplinarity, it can no longer be accepted to face environmental challenges separately from social ones [13]. Both the ecological ground and the internal dynamics of specific communities require to be mapped considering the presence of key players or influencers, the environmental specificities where people live, work and relate, as well as the specific challenges they have to face. This deals with both individual and collective levels, where the latter has recently assumed a greater importance due to the pandemic. Impronta Verde and ReSET project will develop socio-ecological, reflective, monitoring and testing infrastructures to support the adoption of citizen-science-based actions and experimentations. These infrastructures define an open process bridging open knowledge (universal participation, knowledge circularity and knowledge accessibility) and open production (participatory production of new and shared knowledge, co-creation of ideas, projects and contents), without separation integrating citizens in a unique flow of learning, decision making and producing innovation.

References

1. Boeri, A., Longo, D., Gianfrate, V., & Lorenzo, V. (2017). Resilient communities. Social infrastructures for sustainable growth of urban areas. A case study. *International Journal of Sustainable Development and Planning, 12*, 227–237.
2. UN-HABITAT. (2011). *Cities and climate change: Global report on human settlements series: Global report on human settlements*. Earthscan.
3. Carayannis, E. G., & Campbell, D. F. (2009). 'Mode 3' and 'Quadruple Helix': Toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management, 6*(3/4), 201–234.

4. Millennium Ecosystem Assessment. (2005). *Ecosystems and human-well being. A framework for assessment*. Island Press.
5. Andersson, E., Borgström, S., Haase, D., Langemeyer, J., Mascarenhas, A., McPhearson, T., Wolff, M., Łaszkiewicz, E., Kronenberg, J., Barton, D. N., & Herreros-Cantis, P. (2021). A context-sensitive systems approach for understanding and enabling ecosystem service realization in cities. *Ecology and Society, 26*(2), art35. https://doi.org/10.5751/ES-12411-260235
6. Viganò, P. (1999). *La città elementare*. Skira.
7. Comune di Bologna. (2021). *Piano Urbanistico Generale*. Leggere il Piano. http://dru.iperbole.bologna.it/pianificazione?filter=Piano%20Urbanistico%20Generale%20
8. Corboz, A. (1983). Le territoire comme palimpseste. *Diogène, 12*, 14–35.
9. Fondazione Innovazione Urbana. *Fondazione Innovazione Urbana 18–21. Visioni e azioni dell'istituzione dedicata alle trasformazioni di Bologna*. https://www.fondazioneinnovazioneurbana.it/images/PUBBLICAZIONE_FIU/Pubblicazione_FIU_18_21.pdf
10. Mulligan, M., Douglas, C., van Soesbergen, A., Shi, M., Burke, S., van Delden, H., Giordano, R., Lopez-Gunn, E., & Scrieciu, A. (2021). Environmental Intelligence for more Sustainable Infrastructure Investment. In *Proceedings of the conference on information technology for social good* (pp. 225–229). https://doi.org/10.1145/3462203.3475916
11. Nardino, M., Cremonini, L., Georgiadis, T., Mandanici, E., & Bitelli, G. (2021). Microclimate Classification of Bologna (Italy) as a Support Tool for Urban Services and Regeneration. *International Journal of Environmental Research and Public Health, 18*(9), 4898. https://doi.org/10.3390/ijerph18094898
12. ECSA. (2015). *ECSA 10 principles of citizen science*. https://doi.org/10.17605/OSF.IO/XPR2N
13. Gaspari, J., Antonini, E., Gianfrate, V., & Mehmeti, L. (2022). Mapping community environmental capacity to support climate responsive transition. *TECHNE, 23*, 117–126.

The Influence of Individual Comfort in Shaping the Tourism Image of Balige

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1 Introduction

Tourism is one of the leading industries that contribute in providing significant income value for many countries, especially in developing countries [1, 2]. Caldera Toba is part of the UNESCO Global Geo-park. Caldera Toba is also a priority tourism monitored continuously by the Indonesian government. Balige, as the capital of the Toba Regency, is undoubtedly needed for tourism development. On the other hand, sustainability has become a global concern and is increasingly important, especially in the tourism industry [3]. As a result, local governments, tourism businesses, and the tourism industry have adopted the concept of sustainable tourism and believe it is one way to solve tourism problems [4]. Impressions from visitors and residents are essential in tourism because their good or bad images affect their

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satisfaction with a tourist destination [5]. In this case, self-efficacy can play a crucial role in stimulating the perception of good and bad [6].

Self-efficacy beliefs are essential in understanding local people's behavior and tourists' successful organizing, implementing, and completing tasks in the tourism sector [7]. Self-efficacy relies on the social cognitive theory that views a person's cognitive assessment of his ability to complete tasks successfully [8]. In self-efficacy, there are comfort parameters that influence the reason for visits to a destination, such as the economic and the environmental value [9]. Positive self-efficacy identifies that an area has supporting factors; this also becomes a factor of "identification" for the region. It is impossible to create a positive tourist image if the individual's low self-efficacy and vice versa [10].

A tourist destination image is usually defined as a description of a tourist area or a tourist's impression when visiting a tourist area [11]. The tourism image variables are supportive environment, good infrastructure, and good social conditions [12]. Although Balige has interesting tourism qualities, namely its natural beauty and the results of its cultural activities, Balige also has beautiful tourist attractions and is worth a visit. Still, the emerging tourism image does not indicate whether Balige is a comfortable and safe place to go. Also, the condition of the facilities available in Balige, or the community's social and cultural role in Balige's tourism image, is still unclear. Balige and Lake Toba as tourist destinations have not been able to operate maximally. There is insufficient cleanliness in certain areas, limited access to tourist spots, and the unprepared local community as a host [13]. Therefore more in-depth research is needed to show how tourists and residents perceive Balige's tourism image. This research aims to identify whether Balige can provide comfort to tourists and residents, starting from the comfort of its environment, the comfort of the facilities, and the comfort of the social and cultural conditions between tourists and residents. These comfort factors show the tourism image in Balige.

1.1 Comfort

Self-efficacy is related to individual behavior and influences personal practice in performing tasks, affecting their performance [14]. A higher sense of self-efficacy will result in greater satisfaction [15]. Self-efficacy relates to tourist objectives, performance, and the place's comfort [16]. Comfort that occurs will lead to satisfaction with the site [17]. Aside from that, comfort can come from facilities that add comfort (such as trash cans, seats, and public toilets) [2]. The rapid growth of the tourism industry is a reasonably complex challenge in providing a sense of comfort for tourists, especially in developing tourist destinations. The comfort factor in a tourist destination is an added value and an opportunity to be visited by tourists [9].

Comfort is a common trait when carrying out specific behavior [18]. Tourism satisfaction can leave an impression on the region [19]. Happiness comes from comfort, helping potential tourists, and promoting tourism images [10]. Suppose a tourist feels uncomfortable when visiting a tourist area. It can develop a negative impression, seriously damage the regional tourism industry, and cause a loss of interest in the area. If tourists feel discomfort at a destination, they will likely not return to the site and will not recommend the place to others [20].

Comfort can come from a variety of things, from environmental factors in the region to social conditions. Tourism experience also can be unsatisfactory due to various factors. Apart from that, comfort can also influence the self-evaluation of the individual where people in an area measure themselves by giving a positive or negative rating, which means that the place affects their feelings [21]. However, when a tourist feels uncomfortable, it can cause problems for those who are promoting tourism in the area, also for future visitors. Comfort also exists when people are satisfied with their needs to do action rationally and efficiently. This social situation relates to humans' need to control their environment [22].

Comfort defines the need for relief, ease, and transcendence in the four holistic human experience contexts: physical, psycho-spiritual, sociocultural, and environmental [23]. Among several environmental comfort factors, the most important ones are cleanliness, social incivility, air, thermal quality, and crowd in sequence [24]. According to Vischer [25], there are three types of comfort, physical comfort, including safety, hygiene, accessibility, and availability. Functional comfort is defined in terms of environmental support and empowerment to support people le their goals. Psychological comfort, the most abstract and complex comfort level to describe, involves emotions and behaviors caused by the environment. Based on previous research, the researcher concluded three aspects of comfort: Environmental comfort, Physical comfort, and Sociocultural comfort (Table 1).

1.2 Tourism Image

Tourism's image directly affects individuals' overall satisfaction [26]. There is a dynamic reciprocal relationship between individual comfort and the environment, including health problems and supportive surroundings [27]. Individual representations, often labelled tourist images, are the topics most frequently studied in all tourism research [24]. The image plays a fundamental role in tourist destinations' success because it dramatically influences destination choices and tourism satisfaction [28]. The image of tourism is a description of the destination area or tourists' impression when visiting [11]. One factor in marketing tourist destinations has an excellent image to increase tourist arrivals [29]. A positive tourism image influences the interest in visiting again [30].

Table 1 Aspects of comfort

Environmental
Physical
Sociocultural

Table 2 Aspects and factors of tourism image

Aspect	Factor
Environment	Landscape Air quality Water quality Regional cleanliness
Facilities	Accommodation Access roads Parking Public toilet
Sociocultural situation	Social conditions of the community Ethnicity and language Cultural and artistic values

The main factor in building a tourist image is shaping the area's characteristics [31]. The concept of tourism images close relates to tourist destinations' branding that produces a positive image to distinguish them from other tourist areas [32]. In creating or developing a tourist image in an area, the need for attention is not only on one aspect. There is a need for collaboration as a whole consisting of cognitive (perception of the physical nature of a place), affective components (personal feelings and evaluation of the area), component-based, and holistic components. This image will later be known to both tourists and residents. Therefore, image-forming components are based on the harmony between attributes-based (physical) and holistic elements (feeling).

There are several other assessment indicators on environmental aspects, namely, (1) landscape: natural environmental factors available in the area; (2) air quality: has good air quality and does not harm tourists, (3) water quality: has a good flow and supply of water in the region [33]. Physical facilities are lodging facilities, a parking lot, a management room/information center, and public toilets [34]. Other facility indicators include information access, road access, and parking [35].

Social Conditions of the Community

This is related to how local people treat tourists, and it can be in the form of smiles and greetings [36]. Based on previous research, the researcher concluded three aspects of tourism image, Environment, Facilities, and Sociocultural situation, divided into their respective factors (Table 2).

2 Methodology

This research aims to find out how the individual comfort the tourism image in Balige. It should be based on observations of tourists as a whole and also alongside observations with related Balige tourism parties. Based on previous studies, the type of research appropriate for this study is descriptive research using the mix-method. According to previous studies, the data was obtained by observing the field, distributing questionnaires, and conducting interviews [2]. On this basis, the researchers used the same method.

The method was carried out through non-participant field observations, distributing 100 online questionnaires to tourists and local communities measured on a Likert scale of 1–5 (1 = strongly disagree, and 5 = strongly agree), then followed by online interviews with nine related tourism parties/stakeholders in Balige, ranging from two government officials, three stakeholders, two tour guide, and two tourism practitioners. The data in this study were collected for approximately 3 weeks (22 April–17 May). This method obtains more comprehensive, objective, valid, and reliable data. In determining the research location, researchers should consider whether the place already has a tourist image, such as environmental conditions, facilities, and sociocultural conditions. At the same time, examine self-efficacy based on comfort level. This research's comfort is limited to three types of comfort, environmental comfort, physical comfort, and sociocultural comfort. The researcher chose Balige as the study's location and needed tourism development in the Caldera Toba area that the Indonesian government has prioritized. Balige, the Toba Regency capital, certainly plays a vital role in the Toba tourism sector's future growth (Fig. 1).

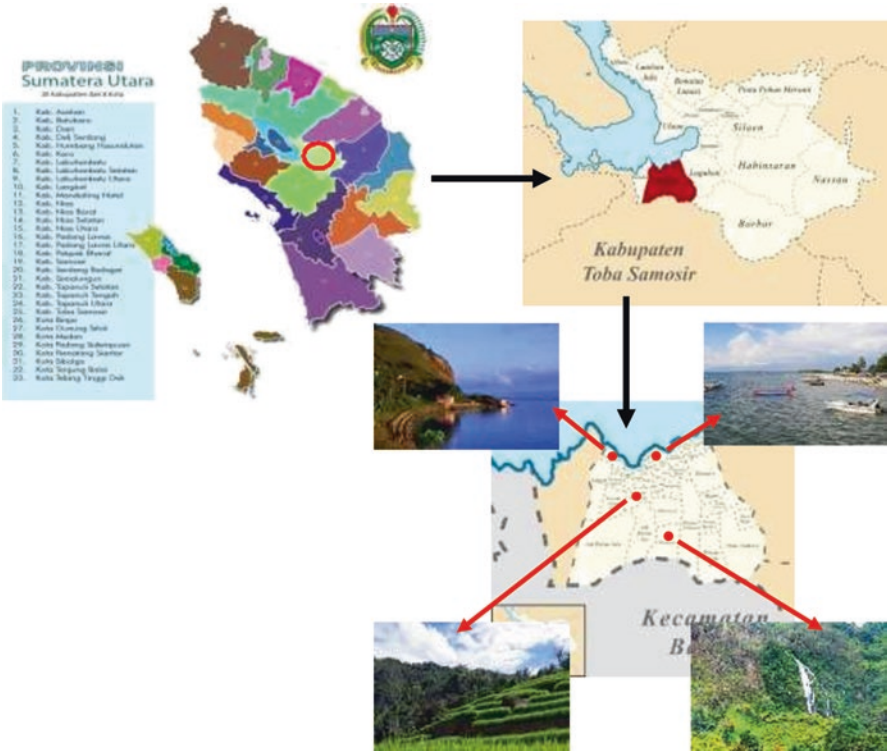

Fig. 1 Research Location in Toba Samosir District, Balige. (Source: Daritoba Project (April 2019))

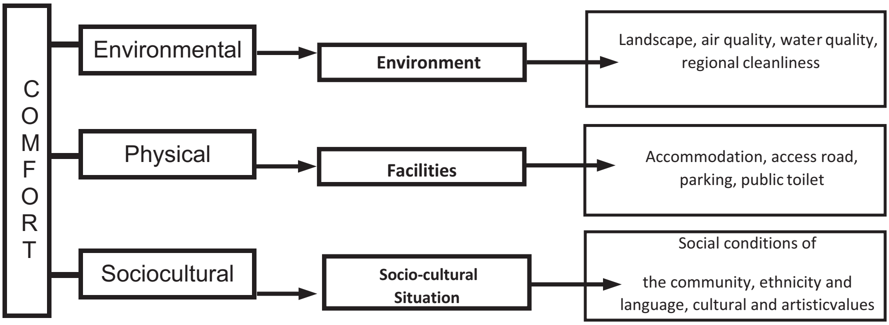

Fig. 2 Comfort diagram based on Tourism Image

The indicators used for each variable are dependent on the interpretation of the indicators from the literature review that has been carried out. Based on that, this study consists of two groups of theories, (1) Comfort (Table 1) and (2) Tourism Image Factors (Table 2). The indicators in the first and second theories are determined based on the aspects and factors in the study library that researchers have interpreted. These two theories lead to three variables, environment, facilities, and sociocultural situation (Fig. 2). Comfort comes from various factors, such as in this study, which measure through the environmental conditions, facilities, and the sociocultural situation in Balige. Furthermore, these three variables divide into their parameters (Fig. 2).

3 Results and Discussion

3.1 *Comfort Aspects Based on the Environment*

Balige, located at the end of Lake Toba, offers natural qualities and attractive environments, ranging from the open air, beaches, and hills to waterfalls. This natural beauty is generally the primary choice of tourists visiting Balige. The comfort level of tourists and residents towards Balige tourism through a questionnaire consisting of four indicators (Table 3). As evidenced by the results of the distribution questionnaires (Table 3), respondents strongly agree on the quality of the environment in Balige, which is very beautiful and exciting (mean = 4.4). One of the motivations for someone to visit a tourist destination is to see the beauty of the landscape [37].

> …so far if I bring tourists, most of them are curious about its natural tourism (Balige), there are tourists that we take to Bul-bul beach, waterfalls, or there are also those who just enjoy the green rice fields here (Balige)…. (Key Respondent: Tour guide Balige)

Each village offers the beauty and diversity of attractive natural areas. Lumban Bul-bul Village, one of the famous spots, is its beach. There are many rides, such as banana boats, solu-solu, and boats to tour around Lake Toba. Then there is also a

Table 3 Comfort aspects by environment

Code	Statement	Tourist	Local residents	Total mean
KL1	The quality of the landscape in the Balige region is beautiful and attracts interest	4.5	4.3	4.4
KL2	Air quality in the Balige region is clean from pollution	4.4	4.3	4.4
KL3	The quality of clean water in the Balige area is good and easy to find	4.5	4.3	4.4
KL4	The environment in the Balige area is clean and well-maintained	2.6	2.7	2.7
Total mean KL		4	3.9	4

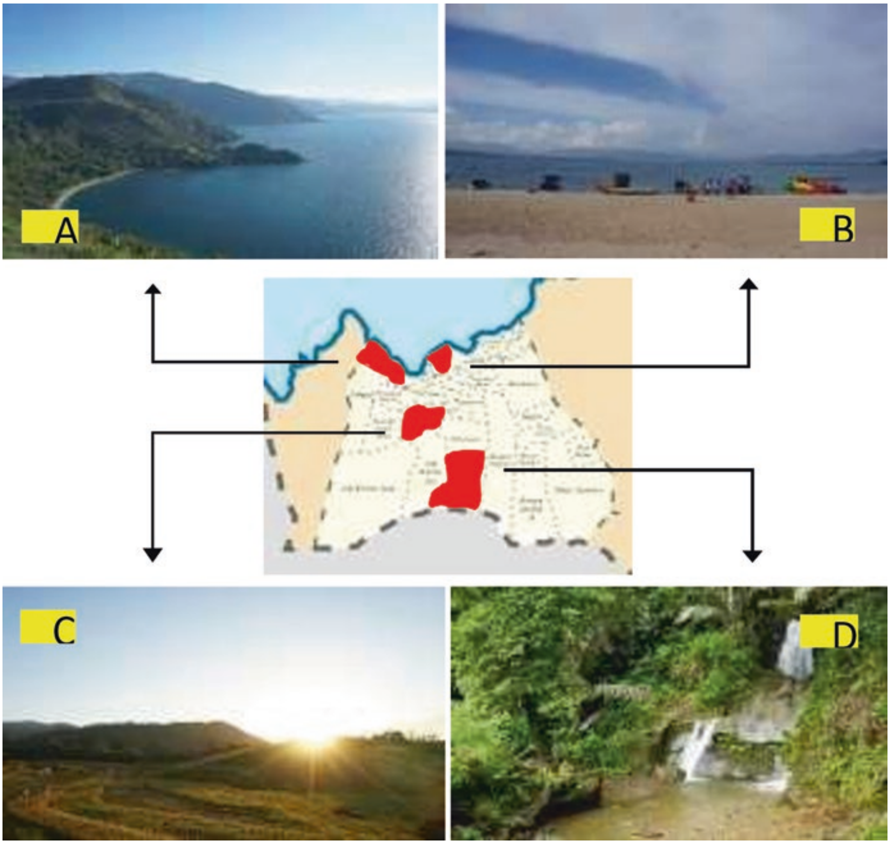

Fig. 3 (**a**) View of Lake Toba in Lumban Silintong Village. (**b**) Lumban Bulbul Beach in Lumban Bulbul Village. (**c**) Rice terraces in Sianipar Sihail-hail Village. (**d**) Siboruon Waterfall in Siboruon Village. (Source: Daritoba Project (April 2019))

beautiful stretch of terraced rice fields, which stretches along the Sianipar Sihail-hail village road. Besides that, there is also a Siboruon waterfall located in the village of Siboruon, and this waterfall is still frequently visited by both tourists and residents (Fig. 3).

In terms of air quality, in Balige itself, the air is not polluted by air pollution. Balige is not an area with factories that can pollute the air and does not occur excessive use of motor vehicles. The sub-district head (Camat) also said the cleanliness of the air in the Balige area,

> …air is never a problem here. Even if there is an air problem, smoke comes from other districts, and if the problem from Balige itself never happened. Besides, we're not a big city full of vehicles and factories, so our air is safe and clean…. (Key Respondent: The sub-district head (Camat) Balige)

As evidenced by the results of the distribution questionnaires (Table 3), the respondents strongly agreed that the air quality in Balige was in good condition and not polluted (mean = 4.4) and supported by the results of observations made in the Balige region. Visible sky without obstacles indicates that the air in Balige is still clean from the pollution, which can disrupt activities in the area (Fig. 4). The level of air pollution in Balige falls into the medium (yellow) category with a 64 AQI US air pollution index.

Then alongside air quality, there is also water quality. In Balige, until now, the water quality is still maintained and evidenced by the results of the distribution questionnaires (Table 3). Where respondents strongly agree that the quality of water in the Balige region is clean and in good condition (mean = 4.4), also supported by the results of observations made in the Balige region. Water quality is in perfect condition, not dirty or smelly. Also, residents often used Lake Toba's clean water for bathing and fishing (Fig. 5).

Fig. 4 Clean air in Lumban Bul-bul Village. (Source: Daritoba Project (April 2019))

Fig. 5 Fishing activities on Lake Toba in Lumban Silintong Village. (Source: Daritoba Project (April 2019))

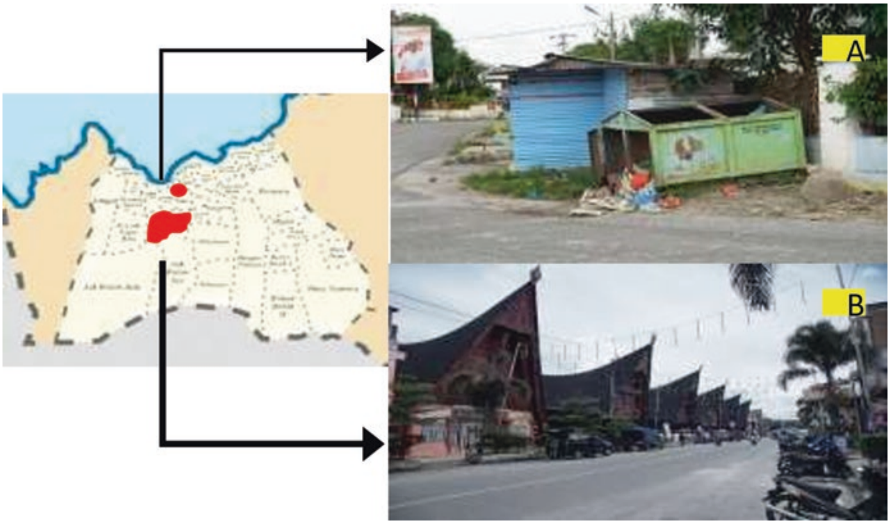

Fig. 6 Environmental cleanliness of Balige. (**a**) Landfill on Siliwangi street. (**b**) Cleanliness of the Balige Onan Market area on Sisingamangaraja street. (Source: Daritoba Project (April 2019))

> …the water quality of Lake Toba is getting better. So far, the smelly Lake Toba water problem has been reduced and does not produce a smell like the previous year…. (Key Respondent: Head of the Environment Agency of Sumatra Utara Province)

The Lake Toba Sustainable Tourism Observatory 2020 states that tourist perceptions of lake water quality in Balige are satisfied (mean = 3.88). In the tourism areas, environmental factors, especially water quality, must be considered to increase the comfort of tourists during the tourism process [38, 39].

The Balige area is relatively clean in some places. However, not all areas have an excellent level of environmental cleanliness (Fig. 6). As evidenced by the distribution questionnaires (Table 3). Respondents disagree that the entire Balige region is in a clean state (mean = 2.7). From the observation, some locations are still poorly maintained, and the trash cans are in a damaged condition, so the existing garbage is scattered. Even though one of the factors that make visitors uncomfortable when travelling is because there is garbage scattered about that is not managed properly [40, 41].

Data obtained from the Lake Toba 2020 Sustainable Tourism Observatory shows that the garbage transport starts from the RT (neighbourhood) garbage can lifted by garbage trucks, then dumped directly into open dumping while there is no adequate sanitary landfill. It shows that garbage management has also not been carried out in a continuity manner to find a pattern of handling garbage with environmental insight. The condition in the area is inconsistent and the cleanliness in Balige is not well-maintained. The sub-district head (Camat) Balige also stated this,

> …for cleanliness in Balige itself, so far it has not been able to be controlled optimally. There are still some areas that can be said to be still not clean, but that doesn't mean we also don't take action, such as broken trash cans which we will gradually repair. In addition, the awareness of the community itself is also vital in orderly disposing of garbage in its place…. (Key Respondent: The sub-district head (Camat) Balige)

3.2 *Comfort Aspects Based on Facilities*

Touristic public facilities include accommodations, toilets, parking lots, and roads. The level of comfort of tourists and residents towards Balige facilities through a questionnaire consists of four indicators (Table 4). In the field of hospitality and tourism, accommodation plays an important role [42]. Accommodation is a fundamental aspect of developing and promoting tourism in the area. The range and quality of available accommodation facilities can reflect how a tourist location is created and entice tourists to choose that destination [43]. In the Balige area, accommodation is not hard to find. Various types of accommodation are available because of the interests of tourists who often visit Balige. These accommodations are maintained

Table 4 Comfort aspects based on facilities

Code	Statement	Tourist	Local residents	Total mean
KF1	Hotels in the Balige area are in a good condition	3.8	4	3.9
KF2	The roads in the Balige region are in a good condition	3.8	4	3.9
KF3	Public parking lots in Balige are in good condition and easy to find	3.7	4	3.9
KF4	Public toilets in the Balige area are in good condition and easily found	2.6	2.6	2.6
Total mean KF		3.5	3.7	3.6

and cared for by each stakeholder concerned so that each accommodation stays in good condition and can continue to run,

> …in Balige, there are various kinds of inns, and in my opinion, they are relatively well-maintained. However, the excellent category depends on the price and the type of accommodation you are looking for…. (Key Respondent: Brussels homestay owner)

Results of distributing questionnaires (Table 4). Respondents agreed that the accommodations in Balige were in good condition and were not damaged or otherwise (mean = 3.9). Observation shows two different types of accommodations: homestays and hotels, and both of these accommodations are among the various inns in Balige (Fig. 7).

Access for tourists to a destination can influence the attractiveness and potential of the tourism destination itself [44, 45]. Access roads in Balige itself are in good condition. Paved and not hollow, even the streets in the village. Even though some roads are not covered, it does not mean the road is damaged and difficult to use. Also shown from the distribution of questionnaires (Table 4), respondents agreed that the road conditions in Balige were in good condition (mean = 3.9). On Sisingamangaraja street, the main route of Balige, the existing road condition is smooth and easy to pass. Likewise, the road conditions in the village of Sianipar Sihail-hail, although it is a village road, are not damaged and are easy to pass for residents and tourists (Fig. 8).

Fig. 7 The state of lodging in Balige. (**a**) Brussels Homestay on D I Panjaitan street. (**b**) Bahagia Hotel on Sisingamangaraja Street – balairung. (Source: Daritoba Project (April 2019))

Fig. 8 Street in Balige. (**a**) Sisingamangaraja Street, Balige. (**b**) Road in the village of Sianipar Sihail-hail. (Source: Daritoba Project (April 2019))

> …the roads in Balige both in the city and the village are pretty good. No road damage can hinder users. Even if there are only minor road damages such as small potholes usually caused by overuse of roads and delays in maintenance due to budget constraints….

In addition to road access, there is also the availability of parking lots. A parking lot is a place to place vehicles, transportation/goods, trains, cars, etc., by stopping at a specific location for a certain period [46]. In the Balige area, we can find parking lots along the roadside. Because the main road in Balige is a two-way lane, the excess shoulder is used as a parking lot, as evidenced by the results of the distribution questionnaires (Table 4), where respondents agree that the condition of the parking lot in the area is excellent and easy to find (mean = 3.9). The results of observations made on Sisingamangaraja Street use both shoulders of the road as a parking lot (Fig. 9). Apart from the road's shoulder, there is also a parking lot provided by the shopkeepers along the road.

Aside from the parking lot, one of the facilities that need to look up to is public toilet facilities. Toilets are one of the human's basic needs, so this infrastructure must consider in developing tourism [47]. The release of the ASEAN Public Toilet Standard (2016) shows awareness of toilets as vital objects. In Balige itself, public toilets' existence is minimal, and it is still quite challenging to find toilets for tourists and residents in the area. The results of the distribution of questionnaires are shown in Table 4, where respondents disagree that the availability of public toilets in Balige is easily found (mean = 2.6). One of the public toilets is the only public toilet located on Lumban Bul-bul Beach. If we need to use the toilet, the only toilet available is in public places such as restaurants, supermarkets, and shops (Fig. 10).

Fig. 9 Parking lots on Sisingamangaraja Street, Balige. (Source: Daritoba Project (April 2019))

Fig. 10 State of public toilets on Lumban Bulbul Beach. (Source: Daritoba Project (April 2019))

> …the availability of public toilets is still lacking. In the future, we will allocate a budget to procure public toilets so that Balige visitors are more comfortable…. (Key Respondent: The sub-district head (Camat) Balige)

3.3 Comfort Aspects Based on Sociocultural Conditions

The Balige area, in terms of social community, shows that the Balige community interacts and socializes well with tourists who visit, measuring tourist and resident comfort levels towards Balige tourism through a questionnaire of three indicators

Table 5 Comfort aspects based on sociocultural conditions

Code	Statement	Tourist	Local resident	Total mean
KS1	Local people welcomed the arrival of tourists well	3.9	4	4
KS2	Race and language differences between residents and tourists do not deter tourists while in the region	3.9	4	4
KS3	Local culture and arts become one of the attractions for tourists	4	4	4
Total mean KS		3.9	4	4

Fig. 11 Interaction between people and tourists. (**a**) Attraction of traditional events at the Hotel Bahagia. (**b**) Buying and selling activities at the Balige Onan Market. (Source: Daritoba Project (April 2019))

(Table 5). It shows from the distribution questionnaires (Table 5), that respondents agreed that local people received tourist arrivals well (mean = 4). The sub-district head (Camat) Balige also stated this,

> …there has never been any rejection from residents when tourists come, and they enthusiastically welcome visiting tourists. The character of the Balinese people is very open and egalitarian. Even though there are differences in the background, it's never been a problem…. (Key Respondent: The sub-district head (Camat) Balige)

Although there are differences in local languages, local people still use Bahasa Indonesia as a universal language for tourists, making it easier for interaction between the two parties. From the results of the questionnaire distribution, the respondents also agreed that even differences in language or ethnicity did not cause problems that hampered tourism activities in the Balige region (mean = 4). The rapid development of the tourism industry can bring understanding between cultures through interactions between tourists and local communities in tourist destinations, even though both have different races and languages [48, 49]. Interactions often occur in the hotel Bahagia area through traditional attractions that tourists can enjoy. Buying and selling activities also happen in the traditional Balige market (Fig. 11).

The community's social conditions can influence the socio-cultural aspect, namely how the community contributes to and socializes with tourists. It can also see in the ethnicity, culture, and language of the people in the region [50]. Regarding race and culture, in Balige, the Toba Batak culture owned by the resident is packaged and sold as tourism products (such as traditional ceremonies) offered to tourists. Tourist often visits this cultural tourism. The distribution questionnaire (Table 5) shows that respondents agreed that Balige's culture and local arts were among the tourist interest to see (mean = 4). From the observations, residents often held celebrations of the Balige independence carnival in the form of a series of processions, Batak dances, and other cultural activities (Fig. 12).

> …Balige is not only famous for its nature but also its culture. Various Batak cultural activities that tourists can enjoy are often a selling point for Balige, such as carnivals and Batak dances at the Bahagia hotel, which tourists often visit. We are thick with a definite culture…. (Key Respondent: The sub-district head (Camat) Balige)

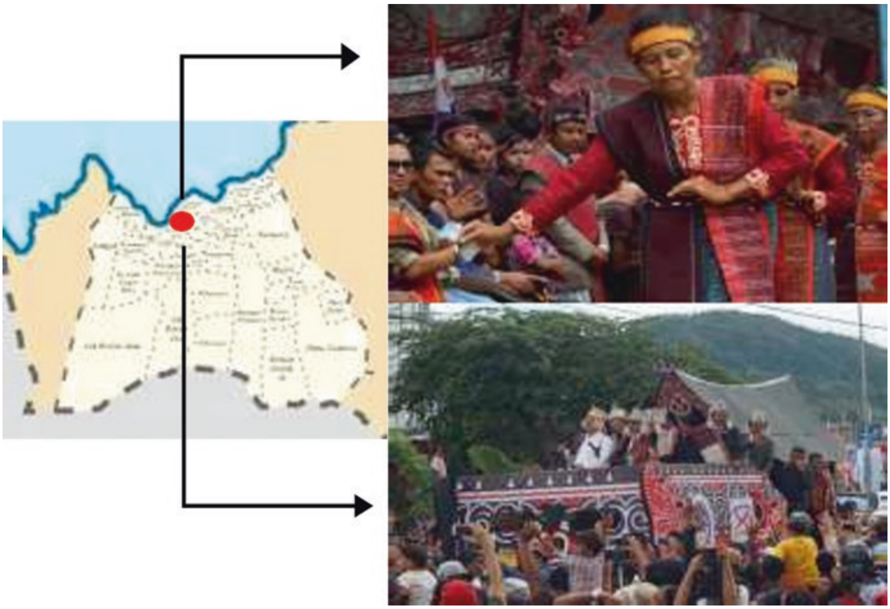

Fig. 12 Celebration of the independence carnival in Balige, often done and enjoyed by tourists. (Source: Daritoba Project (April 2019))

4 Conclusion

The results of this study indicate that positive self-efficacy factors in Balige produce a positive tourism image. The image of tourism in Balige based on the level of environmental comfort, physical comfort, and sociocultural comfort is supportive and positive for tourists and residents. Both respondents felt optimistic about the environmental comfort of the landscape, air quality, and water quality. As for physical comfort, the public facilities on Balige are pretty acceptable. There is also sociocultural comfort between tourists and residents, resulting in both parties being delighted with the interaction. This indicates that Balige tourism's image based on the environment, facilities, and sociocultural is comfortable to visit and does not negatively impact tourists who visit or residents of Balige itself. Nevertheless, if left unchecked, several factors can rise to negative impressions of comfort, namely the Balige area's cleanliness, which is not overly comprehensive, and the lack of public toilets provided in Balige.

The comfort felt by an individual towards a place influences how other individuals' eyes view it. When someone feels positive and comfortable towards an area, the tourism image is also positive, and vice versa. This research shows that the tourism image raised by Balige is good and can bring comfort to tourists and residents, which puts Balige‘s tourism sector in a good direction. However, if not considered in the future, several factors can decrease the quality of comfort towards Balige, such as the area's cleanliness is still not optimal. Comprehensive management between the government, residents, and tourists is needed to keep Balige clean. Nowadays, garbage is still considered unimportant and valuable, so there is no effort to compost or recycle it. The need for strong cooperation between the residents and the Balige government to maintain cleanliness can start by making detailed regional regulations (Perda) regarding garbage, and the community can apply. Besides, it can be done through a social approach in the form of advice, counseling, and also guidance to the local community on how important it is to maintain cleanliness. On the other hand, there is also a need for physical, structural, and orderly garbage management planning, such as sorting garbage by providing different trash cans according to the garbage characteristics. Alternatively, it simply starts by creating good garbage dumps that are not easily damaged and are durable.

Aside from that, there is also a lack of accessible public toilets in Balige. Public toilets are one of the public facilities that should be easy to find, especially in tourist destinations. Likewise, with the Balige government, practitioners and anyone involved in planning public facilities distribution should create public toilets that can increase individual comfort in the Balige area. Public toilets that provide plentiful water supplies and other clean, safe, and hygienic equipment should be available in every public building and every tourist spot in Balige, which is very much needed to maintain comfort in Balige. Architecture can also affect the comfort and image of a tourist destination. Architecture, in general, is in direct contact with the physical form. This research shows that the physical comfort factor is less supportive in public facilities (public toilets) and environmental comfort in cleanliness where they lack cleanliness in certain areas. These two discomforts certainly need architectural practitioners' points of view to resolve them without destroying Balige's natural beauty.

This paper limits the research based on individual comfort towards the tourism image in Balige, so there is still a need for further research on the primary comfort factors that a tourist destination needs to project a comfortable feeling. Moreover, can comfort becomes the primary basis for determining a tourism image?

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References

1. Ginting, N., Rahman, N. V., Nasution, A. D., & Wahid, J. (2021). Particular characters in heritage tourism to attract visitors: A comparative study in Sumatra, Indonesia. *Environment-Behaviour Proceedings Journal, 6*(18), 205–210.
2. Ginting, N. (2016). How self-efficacy enhance heritage tourism in Medan Historical Corridor, Indonesia. *Procedia – Social and Behavioral Sciences, 234*, 193–200.
3. Fong, S. F., Lo, M. C., Songan, P., & Nair, V. (2017). Self-efficacy and sustainable rural tourism development: Local communities' perspectives from Kuching, Sarawak. *Asia Pacific Journal of Tourism Research, 22*(2), 147–159.
4. Bramwell, B., & dan Lane, B. (2000). Collaboration and partnerships in tourism planning. In B. didalam Bramwell & B. dan Lane (Eds.), *Tourism collaboration and partnerships: Politics, practise and sustainability* (pp. 1–19). Channel View Publications.
5. Ginting, N., Rahman, N. V., & Nasution, A. D. (2022). Impact of gender on self-efficacy: Evidence From Indonesia's Karo Tourism. *GeoJournal of Tourism and Geosites, 40*(1), 218–224.
6. Ginting, N., Rahman, N. V., & Nasution, A. D. (2017). Increasing tourism in Karo District, Indonesia based on place identity. *Environment-Behaviour Proceedings Journal, 2*(5), 177–184.
7. Fong, R. W., & Yuen, M. T. (2016). The role of self-efficacy and connectedness in the academic success of Chinese learners. In *The psychology of Asian learners: A festschrift in honor of David Watkins* (pp. 157–169). Springer.
8. Medrano, L. A., Flores-Kanter, E., Moretti, L., & Pereno, G. L. (2016). The effects of induction of positive and negative emotional states on the beliefs of academic self-efficacy of university students. *Psicologia Educativa, 22*(2), 135–141.
9. Khalik, W. (2014). Kajian Kenyamanan Dan Keamanan Wisatawan Di Kawasan Pariwisata Kuta Lombok. *Jurnal Master Pariwisata (JUMPA)*, 1–13.
10. Costa, C. (2006). Conclusion: Tourism management dynamics. *Tourism Management Dynamics*, 247–252.
11. Nassar, M. A., et al. (2015). Factors influencing travel to Islamic destinations: An empirical analysis of Kuwaiti nationals. *International Journal of Culture, Tourism, and Hospitality Research, 9*(1), 36–53.
12. Gomez, M., Lopes, C., & Molina, A. (2015, December). A model of tourism destination brand equity: The case of wine tourism destinations in Spain. *Tourism Management, 51*, 210–222.

13. Marpomari Mahulae, P. (2019). Deskripsi Permasalahan Upaya Pengembangan Pariwisata Berkelanjutan di Danau Toba Sumatera Utara (Problem description of sustainable tourism development effort on Toba Lake North Sumatera). *Inovasi, 16*(1), 11–20.
14. Zhou, T. (2011). An empirical examination of initial trust in Mobile banking. *Internet Research, 21*(5), 527–540.
15. Jin, X., et al. (2016). How do worry, self-efficacy, and coping interact? Examining Chinese tourists to Australia. *Journal of China Tourism Research, 12*, 374.
16. Klassen, R., & Chiu, M. (2010). Effects on teachers' self-efficacy and job satisfaction: Teacher gender, years of experience, and job stress. *Journal of Educational Psychology, 102*, 741–756.
17. Ujang, N. (2012). Place attachment and continuity of urban place identity. *Procedia-Social and Behavioral Sciences, 49*, 156–167.
18. Hung, K., & Petrick, J. F. (2012). Testing the effects of congruity, travel constraints, and self-efficacy on travel intentions: An alternative decision-making model. *Tourism Management, 33*(4), 855–867.
19. Nisco, A. D., Mainolfi, G., Marino, V., & Napolitano, M. R. (2015). Tourism satisfaction effect on general country image, destination image, and post-visit intentions. *Journal of Vacation Marketing, 21*(4), 305–317.
20. George, R. (2003). Tourist's perceptions of safety and security while visiting Cape Town. *Tourism Management, 24*(5), 575–585.
21. Ginting, N., Rahman, N. V., & Nasution, A. D. (2019). Aspects of self-esteem in the tourism development in Karo regency, North Sumatera, Indonesia. *Journal of Urban and Regional Analysis, 11*(2), 173–183.
22. Peattie, S., Clarke, P., & Peattie, K. (2005). Risk and responsibility in tourism: Promoting sun-safety. *Tourism Management, 26*(3), 399–408.
23. Rosier, P. K. (2005). Comfort theory and practice: A vision for holistic health care and research. *Clinical Nurse Specialist, 19*(1), 49.
24. Dolnicar, S., & Grun, B. (2013). Validly measuring destination image in survey studies. *Journal of Travel Research, 52*(1), 3–14.
25. Vischer, J. C. (2007). The effects of the physical environmental on work performance: Towards a model of workspace stress. *Stress and Health, 23*(3), 175–184.
26. Chen, C.-F., & Tsai, D. C. (2007). How destination image and evaluative factors affect behavioral intentions? *Tourism Management, 28*(4), 1115–1122.
27. Stokols, D., & Clitheroe, C. (2010). Environmental psychology and environmental health. In H. Frumkin (Ed.), *Environmental health: From local to global* (2nd ed., pp. 137–171). Jossey-Bass Publishers.
28. Prayag, G., & Ryan, C. (2011). Antecedents of tourists loyalty to Mauritius: The role and influence of destination image, place attachment, personal involvement, and satisfaction. *Journal of Travel Research, 51*, 342.
29. Chiu, W. Z., & Cheng, P. (2016). The influence of destination image and tourist satisfaction on tourist loyalty: A case study of Chinese tourists in Korea. *International Journal of Culture, Tourism and Hospitality Research, 10*(2), 223–234.
30. Tan, W. K., & Wu, C. E. (2016). An investigation of the relationships among destination familiarity, destination image, and future visit intention. *Journal of Destination Marketing and Management, 5*(3), 214–226.
31. Foroudi, P., Akarsu, T. N., Ageeva, E., Foroudi, M. M., Dennis, C., & Melewar, T. C. (2018). Promising the dream: Changing destination image of London through the effect of website place. *Journal of Business Research, 83*(October 2017), 97–110.
32. Souiden, N., Ladhari, R., & Chiadmi, N. E. (2017). Destination personality and destination image. *Journal of Hospitality and Tourism Management, 32*, 54–70.
33. Spenceley, A. (2005). Nature-based tourism and environmental sustainability in South Africa. *Journal of Sustainable Tourism, 13*(2), 136–170.
34. Spillane, J. (2000). *Ekonomi pariwisata: sejarah dan prospeknya*. penerbit kanisius.
35. Soekadijo, R. G. (2003). *Anatomi pariwisata*. penerbit gramedia pustaka utama.

36. Waani, H. F. (2016). Sosial Budaya Dalam Pengembangan Pariwisata Di Kelurahan Bunaken Kecamatan Bunaken Kota Manado. *Acta Diurna, V*(2).
37. Ngwira, C., & Kankhuni, Z. (2018). What attracts tourists to a destination? Is it attractions? *African Journal of Hospitality, Tourism and Leisure, 7*, 1–19.
38. Ying, A. N. (2015). Tourism development and ecological environment protection. *Journal of Landscape Research; Cranston, 7*(1), 43–44.
39. Sun, Q., & Liu, Z. (2020). Impact of tourism activities on water pollution in the West Lake Basin (Hangzhou, China). *Open Geosciences, 12*(1), 1302–1308.
40. Atmanti, H. D., & Purwanti, E. Y. (2021). The impact of waste on domestic tourist visits to Pangaradan Beach, Banten Province. *International Journal of Economics, Business and Accounting Research (IJEBAR), 5*(2), 399–406.
41. Ginting, N., Rahman, N. V., & Trombadore, A. (2021). Conservation aspects on developing geotourism for young tourists during the COVID-19 pandemic in Silalahi Village. *Environment-Behaviour Proceedings Journal, 6*(18), 193–203.
42. Nutsugbodo, R. Y. (2016). Tourist accommodation. In O. Akyeampong (Ed.), *Tourism development in Ghana's Brong-Ahafo region: Demand and supply dynamics* (pp. 73–88). Xtrym Consortium.
43. Pertiwi, P., & Sulistyawati, A. (2020). Factors of influence in choosing accommodation: A study with reference to mas village, an artistic heritage village in Ubud – Bali. *Journal of Business on Hospitality and Tourism, 6*(1), 27–42.
44. Virkar, A. R., & Mallya, P. D. (2018). A review of dimensions of tourism transport affecting tourist satisfaction. *Indian Journal of Commerce and Management Studies, 9*(1), 72–80.
45. Ginting, N., Rahman, N. V., & Husna, N. (2022). Exploring distinctiveness in religious tourism through landmark: A study of place identity in Langkat, North Sumatera. *International Journal of Education and Social Science Research (IJESSR), 5*(4), 52–63.
46. Aliyah, I., & Aulia, S. A. S. (2019). The flexibility of parking space of traditional market in the City Center (Case Study: Pasar Gede of Surakarta, Indonesia). *IOP Conference Series: Earth and Environmental Science, 328*(1), 0–9.
47. Nevelyn, J., & Aruan, D. T. H. (2020). Toilet matters. In *Proceedings of the international conference on business and management research (ICBMR 2020)* (pp. 211–217, 2352–5428). Atlantis Press.
48. Priono, Y. (2011). Studi Dampak Pariwisata Bukit Batu Kabupaten Kasongan Ditinjau Dari Aspek Ekonomi, Sosial dan Budaya. *Jurnal Perspektif Arsitektur, 6*(2).
49. Dipadewanda, I., & Mahagangga, I. (2019). Perkembangan Pariwisata Di Daya Tarik Wisata Pantai Berawa Kabupaten Badung. *Jurnal Destinasi Pariwisata, 6*(2), 309–313.
50. Cole, S. (2007). *Tourism, culture and development: Hopes, dreams and realities in East Indonesia*. Channel View Publications.

Feasibility of Integrating Small-Scale Anaerobic Digestion in Urban Areas: Analyzing Energy Efficiency

Antonio Morán, Marcos Ellacuriaga, Daniela Carrillo-Peña, and Xiomar Gómez

1 Introduction

The current economic model is receiving a lot of critics due to the huge amounts of resources involved and the volume of residues generated following a linear path of production and waste generation with limited possibilities of reintegrating resources into the economic chain. The concept of the circular economy has as the core defining element the "restorative use" of resources; thus raw materials should be transformed into valuable products and avoid becoming discarded waste [1]. However, this concept which may seem relatively easy to define, and finds a great share of acceptance in public opinion, is difficult to implement in the current economic model and in daily social activities. The concept must confront the limits of reality and thermodynamic laws, thus cycling activities have an inherent increase in entropy resulting in an increased energy demand to keep the quality of elements at a high level [2, 3].

The reduction in the amount of waste produced and valorization or the reintegration of lower quality material into the production chain should take into account the dispersion of the material, transportation costs, and all different treatment units involved in recovering valuable components and equipment associated with its transformation [4]. To these constraints, other requisites should be considered as it is religious beliefs, health risks, and social concerns regarding the acceptance of by-products.

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The substitution of fossil fuels and mitigation of CO_2 emissions are also aspects linked with the circular economy model. Renewable energies are to play a major role in future energy solutions. However, factors such as seasonality, dispersion and lack of accumulation results are relevant to guaranteeing energy security. The Landfill Directive in 1999 (European Commission, 2008/98/EC) was decisive in optimizing waste management policies by setting priority on waste prevention. Recently Directive (EU) 2018/851 was conceived with the aim of helping to increase synergies between the circular economy and energy, climate, agriculture, industry and research policies, bringing benefits to the environment in terms of greenhouse gas emission savings and to the economy [5, 6].

It seems clear the interconnection of different activities and the way several aspects of the economy should be interrelated with environmental impacts, energy solutions and efficiency maximization in the use of raw materials. A way of optimizing resources and limiting emissions is the encouragement of the local economy and decentralized production and treatment centers. However, the small scale of these systems will go against it. This is the case of decentralizing services in urban areas and residential sectors. There exist different alternatives for producing renewable energy such as wind turbines, and solar panels to produce heat or electricity (solar thermal or solar photovoltaic), with the latter experiencing fast growth thanks to the significant reduction in installation costs and the easiness of decentralized operation covering a wide variety of scales [7]. The use of biomass for producing energy is another example of the adaptation of technology to cover different demands for producing heat and electricity. Large-scale biomass thermal power units for electricity production are under operation in Spain (tecpa.es) and this technology is experiencing a great expansion worldwide thanks to its great transferability capacity to developing countries [8, 9]. Small biomass units for individual family residences are also another share of the biomass technology but in this case for producing heat and hot water services. This market has also experienced a great expansion, due to the versatility of biomass boilers, but the production of electricity in this case is dominated by centralized thermal units with higher efficiency.

Technologies capable of producing energy (heat and electricity) and valorizing wastes at the same time have not experienced the same level of expansion and adaptation to different scales. This is the case with anaerobic digestion. This technology is widely recognized as an environmentally friendly option for the conversion of organic wastes into methane and valuable organic amendments allowing the recycling of nutrients into the agricultural sector [10, 11]. However, the European market is mainly dominated by large-scale centralized units due to high installation and operating costs, along with the need for highly skilled personnel for the maintenance of these units. Other factors limiting the spreading of this option is the lower productivity attained at smaller scales and under high-solid configurations thus limiting profit margins [12]. On the contrary, in rural areas worldwide and in developing countries, the majority of anaerobic digesters are associated with treating wastes from single households but some of these installations experience operating problems and failed to keep running in the long term [13, 14].

Microbial cells are another type of technology capable of transforming organic materials into valuable products (energy and/or chemical compounds) but further development at a larger scale has proven insurmountable. Thus, the technology is still under a laboratory-scale offering promising results that lack application at an industrial scale due to difficulties in achieving stable performances under real operating conditions [15, 16]. Several operating challenges need to be overcome as it is biofouling of surfaces, unstable long-term performance, low efficiency and high cost of components [17].

The present document examines the state of the art of small-scale digestion and the feasibility of applying this technology in the residential sector under different scenarios considering climatic conditions and different types of residential configurations.

2 Types of Small-Scale Anaerobic Digesters and Main Performance Parameters

Anaerobic digestion is a technology well developed with several commercial companies offering solutions to different scales. Small-scale digestion systems can be operated under low and high solid content configurations. Wet digestion is usually performed under continuously stirred reactors (CSTR) with low solid content and agitation provided by mechanical means. However, this type of operation limits productivity due to the high-water content. Increasing the organic loading rate (OLR) may lead to higher biogas production in terms of reactor productivity but this higher loading also results in lower methane yield thus reducing the efficiency of the degradation [18]. The OLR can be increased either by modifying the solid content of the feeding substrate or by reducing the hydraulic retention time (HRT) under this type of operating conditions. Tubular reactors operating under plug flow mode are widely employed due to their simplified design and absence of moving parts. To compensate for the absence of active mixing the volume of the reactor is increased to allow greater residence time inside the digester.

Other reactor configurations include solid-state fermentation, where solid content is greater than 20% TS. The operation of these systems required loading and unloading stages, with inoculation becoming a relevant factor in the development of biodegradation. The system must operate then under batch conditions and those performing fermentation by means of a percolating configuration required an additional tank for storage of percolate rich in active methanogenic microflora [19].

The main parameters for evaluating anaerobic digestion performance consider specific methane production (SMP) which gives the volume of methane produced per mass unit of solid fed into the reactor. Another parameter evaluating efficiency is the volumetric methane production of the reactor, which indicates the daily volume of gas produced per unit of reactor volume. Alkalinity and pH aid in monitoring the evolution of the process and allow for predicting possible fermentation imbalances due to excessive organic loading or changes in the biodegradability of the feed. Temperature affects the degradation rate, thus the reactor must be kept at a constant temperature with this being accomplished by a heating system and insulation to reduce heat losses.

2.1 Material and Methods

2.1.1 Digestion Plant Configuration

The analysis is performed by considering two different climatic conditions and evaluating the energy demand for single houses and extrapolating this demand to a local community. The production of food wastes and garden wastes were the main substrates considered susceptible to valorization by anaerobic digestion. The rate of food production was used as the main parameter to estimate the volume of the reactor needed and the production of biogas expected. The minimum working volume of the anaerobic reactor was 6 m^3 with a headspace of 30% of the total reactor volume. The volume of the digester was estimated by assuming an HRT of 35 days when temperature control is provided for the biological process, whereas this parameter was increased to 80 days when lacking thermostatization. Continuous operation was considered for reactors operating under wet configuration.

Dry digestion was assumed when garden wastes and community parks are integrated into the area of service of the digester. The amount of biogas produced was based on methane yield values reported in the literature for food wastes and grass material. When data are derived from biochemical methane potential (BMP) tests a correction factor of 40% was applied to take into account changes in reactor dynamics due to continuous operation, thus lowering biogas production.

Gómez et al. [20] and González et al. [21] reported an average value of 340 mL CH_4/g VS when operating under semi-continuous conditions and an HRT between 40 and 20 days. Cabbai et al. [22] reported values obtained from BMP tests for restaurants and canteen organic wastes of 571–675 mL CH_4/g VS, thus in order to extrapolate to continuous conditions an average value of 357.6 mL CH_4/g VS was considered. The mean value used for calculations was then 349 mL CH_4/g VS. The total solid (TS) content of food waste was 152 g/L with 90% content of VS, using data reported by Brown and Li [23]. The methane yield of garden and grass lawn wastes was assumed as 340 mL CH_4/g VS under batch conditions [24], using a value of 203 mL CH_4/g VS under continuous conditions. For garden wastes, a yield of 185 mL CH_4/g VS was assumed (equivalent to 111 mL CH_4/g VS for continuous conditions) [25].

The mass of digested material and water content was estimated by a mass balance over the digester. Inorganic solids were assumed to keep constant during biological degradation. Gas produced is used to cover household demand for domestic hot water and heating. The lower heating value (LHV) of methane was 35.8 MJ/m^3.

2.1.2 Description of Scenarios

The energy demand of residential housing was estimated as 5233 kWh/year per home for covering sanitary hot water and space heating needs [26, 27] considering that 75% of this consumption is produced in the autumn-winter period, and the remaining value was for the spring-summer period. Scenario 1 represents the case of housing in residential buildings of 6 stories on average with a number of 4 flats per story. The average production of food waste assumed was 77 kg/year per capita for Spain (with a total waste production of 442 kg/year per capita) [28, 29]. A number of 3 individuals per flat was considered. The daily volume of water consumption was 136 L/inhab. day [30]. 8% of urban soil was assumed to be dedicated to green public gardens and community parks [31]. Values of garden waste and food waste for Spain were 187 kg/person-year [32].

Scenario 2 represents the case of single-detached housing with higher number of family members (5). This scenario was evaluated for low-populated regions with the housing comprising a space of 500 m^2 with the ground floor having 150 m^2. The total space for estimating heating demand would be 300 m^2. Garden waste production was assumed as 1.96 ± 1.35 kg/person d [33]. Two types of reactor configurations were considered. The first one was a high-solid reactor working under batch conditions at 20% total solid in staggered mode. The second reactor was a leachate bed percolating system operating at an initial 50% TS, also under batch conditions. In this latter case, a bioelectrochemical system (BES) was integrated to aid in the treatment of the percolating liquid.

Scenario 3 studies the energy production from small digesters covering the treatment need for organics produced by single housing and small farms in tropical regions of developing countries. In the present case, a single family of 8 members was considered (4 adults – 4 children), assuming no food waste production, since this material is commonly used to complement animal feeding. Garden wastes were also disregarded in this case due to the configuration of the digester assumed. The type and number of animals belonging to the family members were assumed in this case as, 20 hens, 4 pigs and 3 cows. Animal manure and human feces were digested in a simplified fixed dome reactor with a hydraulic retention time of 80 days. The total solid content of the digester feed was fixed at 60 g/L. The production of human feces was 400 g/person-day and 800 mL/person day for adults and half this value for kids. Laying hens were assumed to generate 162 g/hen day. The production of manure for pigs was 19.2 kg/pig day and 55 kg/cow day for cattle.

2.2 Results and Discussion

2.2.1 Scenario 1

Scenario 1 considers residential housing and the treatment of community wastes from each building. Figure 1 indicates major assumptions and results derived from this scenario. The annual food waste production for each building was estimated at

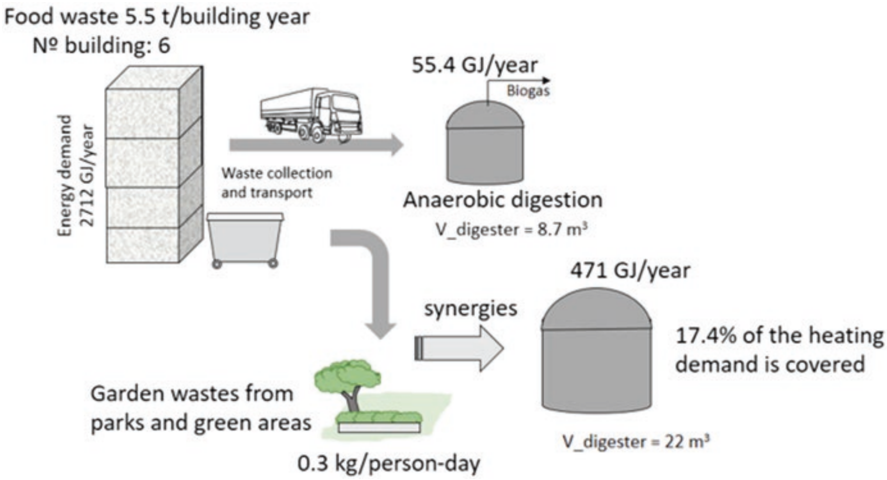

Fig. 1 Main assumptions considered for Scenario 1 evaluating residential housing in highly populated areas

5.5 t/year. Thus, using assumptions established in the material and method section, the working volume of the digester needed for treating the mass of waste generated by 6 residential buildings will be 6.1 m^3, thus the total volume considering the head-space would be 8.7 m^3.

The amount of biogas produced would account for 55.4 GJ/year (15,300 kWh/year). However, this quantity results insignificant if compared with the amount of energy needed for these same houses which accounts for 2712 GJ/year for covering the demand for heating and sanitary hot water. The energy demand of Finland housing was studied by Heinonen and Junnila [34] reporting values for total energy consumption ranging between 15,000 and 23,500 kWh/year per housing, making the difference between detached houses with the greatest energy demand and flats, having the lower energy demand. These data, although reporting total energy consumption (more than 60% of this energy demand represents heating demand), give an idea of the implications of weather conditions and energy needs in different climatic areas. One aspect which is relevant to take into account is that although detached houses present greater energy demand, the number of members housing is much greater; therefore, resulting in more efficient energy living systems when considering energy demand per capita.

Given the low capacity for producing energy from wastes and covering the demand for residential housing, other substrates would need to be available for producing enough amount of energy locally. Therefore, if garden wastes were to be considered, the material available would be obtained from a surface equivalent to 0.2 km^2 for a high-density populated area as would be the case of Madrid with a mean population density of 2181 inhab/km^2 in the urban area. If a less populated region is assumed as it would be the urban area of Léon (466 inhab/km^2), then a surface equivalent to 0.93 km^2 would be available for housing.

In the present study, an average production of 0.3 kg/person-day of garden waste was assumed. Values of green wastes reported for England housing, when considering urban areas, were about 0.64 ± 0.46 kg/person-day. This value increases to 1.96 ± 1.35 kg/person d when considering rural areas [33]. Other authors reported lower values, 0.365 kg/person-day for Denmark [35]. Given the scarcity of studies regarding garden waste collection and characterization, the mean value considered here was increased by 30% for low-populated areas and reduced in this same amount for highly populated areas. Therefore, a range of values was obtained for the amount of extra energy derived if this material is used as a co-substrate. As a gross approximation, the maximum volume of biogas produced for garden waste would be in this case 2870 m^3 of extra biogas, if values of methane production reported by Zhang et al. [25] are used.

This increase in gas production only covers 5.8% of the total needs of an average house for heating and domestic hot water. These approximations were obtained by only estimating global gas production without considering relevant factors that play a crucial role in the feasibility of these alternatives as it is, the transport of wastes, preparation of feeding, and by-product disposal. These subjects are crucial and will be treated in future work. The effect of applying a higher organic loading rate and the size needed for the reactor determines the space needed for the decentralized treatment unit. Taking into account that the alternative is configured for urban areas, the available space inside the city for the installation of these plants is a relevant constraint.

The addition of garden wastes to an anaerobic digestion system must consider the type of reactor operation. Previous estimations assumed no synergies between different substrates. However, it has been reported by several authors that co-digestion may allow an increase in the global production of the mixtures thanks to the better nutrient balance attained [36–39]. In fact, Fitamo et al. [40] reported a yield ranging from 287 to 433 mL CH_4/g VS when operating at OLR between 0.65 to 5.0 g/Lr day with HRT as low as 14 days under continuous operation. These yields are much higher than those obtained from previous estimations. If recalculating and considering these higher yields, then for the mixture of garden and food waste an energy production of 471 GJ/year would be estimated for the most favorable case which would cover 17% of the energy demand studied.

However, this later consideration implies operation under low solid content for the feed which would translate into excessive demand for water and digestion volume. That is, garden waste has a high solid content and this material would need dilution if used as a co-substrate in a CSTR configuration. Methane yields used in previous calculations were based on a high solid reactor configuration, explaining thus the lower values reported which are associated with mass transfer limitations and accumulation of inhibitory compounds. Calculating the size of the digester for an OLR of 5 g VS/Lr d, the working volume would be 17 m^3 (total volume of 22 m^3) when operating at lower solid content.

Even though reactor productivity may be increased by the addition of the co-substrate if the best scenario is assumed (reactor productivity was 9.2 GJ/year m^3r whereas the addition of co-substrate translates into 27.7 GJ/year m^3r, due to the hypothetical increase expected in methane yield), several aspects need still to be considered prior to validate such approach and one of the most relevant ones would be the urban space available for introducing this type of installation into the city configuration. For a population of 150,000 inhabitants, approximately 350 units of this type would be needed which sets great pressure on the use of soil in cities with high population density. Thus, the alternative of decentralization seems unreasonable for this scenario. Although the availability of additional co-substrates would increase reactor productivity, this assumption would translate also into a higher digester size. To the previous statement, should also be added the fact that garden waste availability is mainly produced during spring-summer periods, therefore accumulation of this material would be necessary to guarantee a continuous feeding to the digester all year round, translating into higher requirements for space due to storage, but the higher thermal demand for heating takes place in winter and digesters are not flexible enough to run under different loading conditions to produce the amount of energy demanded.

2.2.2 Scenario 2

This scenario considers single-detached housing located in the vicinity of urban areas or in regions where the density population is low. If a digester is considered for treating waste from a single-family unit with 5 members, then a food waste production of 385 kg/year should be considered. Under these same assumptions, the mass of garden waste produced would be 3577 kg/year. Figure 2 presents a

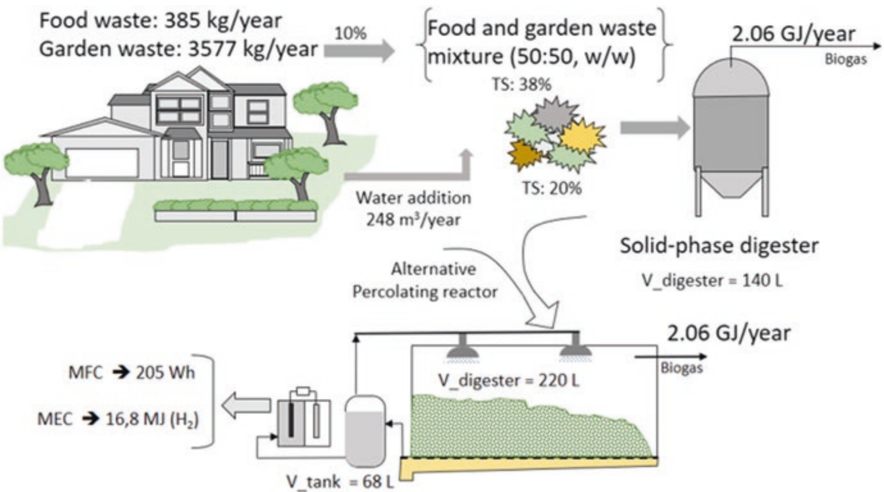

Fig. 2 Main assumptions considered for Scenario 2 evaluating single detached housing in low populated areas by considering high solid-phase digestion and leachate percolating bed reactor

schematization of the main parameters considered in this scenario and the energy produced from different reactor configurations.

Given the wide differences in the amount of food waste produced and the mass of garden waste generated, it was considered that only a proportion equivalent to the mass of food waste was used as co-substrate under a solid phase configuration reactor operating at a solid content of 20% TS. The remaining garden waste material would then need to find other treatment options as it would be composting.

Under assumptions considered then the mixtures of food and garden waste would result in a TS content of 38%, needing dilution with water. Thus, a source of water is necessary to attain the operation of the digester. Wastewater from the same residence may be used for attaining the TS content required. The additional volume of water needed would be 670 L/year. This quantity is easily obtained from the daily wastewater production in developed countries. For the present case, with daily water use of 136 L/inhab day, the volume of water used is 248 m^3/year. However, this issue is of great concern in dry regions where water is scarce and only basic needs are covered. This is the case of the National Domestic Biogas Program (NDBP) which was invested in 2007 with an initial budget of $14.1 million. This program intended to develop the Rwandan biogas sector by building 15,000 family-sized biogas plants.

Many factors negatively affected the success of the program, the evident ones are associated with the complexity of the technology and the lack of skilled personnel. However, a fundamental problem was the scarcity of water which is necessary to attain the required solid content for the process to be run at a determined configuration [41]. Even in this case, a high solid configuration running at 20% TS solid content still a great volume of water needs to be added if the material itself does not have the necessary moisture. Operating at higher solid content was demonstrated to cause a decrease in biogas yield and higher operating times due to the accumulation of acid-inhibitory compounds [12, 42]. Many solid-state digestion systems work with leachate recirculation, but this regimen implies an increase in reactor volume to hold the bulking material to create a percolating bed [43, 44].

For simplification, here was assumed a batch reactor operating under a high solid-phase configuration. This type of working condition implies a time needed for loading and another phase needed for completing digestion. Then two reactors are to be built to keep one in the final digestion phase, whereas the other one is receiving material daily. In addition, the lack of mixing implies the preparation of inoculation prior to feeding the material with digestate derived from the maturation phase. Thus, a total working volume of 108 L was estimated for each reactor. Each digester would have a loading capacity of 31.6 kg of the mixture of food and garden waste, treating this material in a global time of 30 days if temperature control is provided. The increase in retention time for the reactor would translate not only into higher digester volumes but also into a higher number of digesters for treating the yearly amount of material.

The maximum gas production that would be obtained under the configuration considered would be 57.6 m^3 of methane (2.0 GJ/year). Just as in the previous case, the energy produced is too low to compensate for heating demand for a family house (needs 20–60 GJ/year). Many aspects of the calculation are here omitted to set the focus on the volume of gas produced from the reactor. Even though not all aspects regarding auxiliary equipment are taken into consideration, the most favorable case is already reporting low energy yields, then considering, reactor heating requirement and electric demand of all auxiliary devices will just worsen the global result. If climatic conditions are to be those of tropical countries with mild temperatures all year round, then the thermal demand of the digester would be disregarded, and operating at ambient temperature wouldn't result in an excessive increase in reactor volume. Therefore, the gas produced would be used only for covering the fuel demand for cooking since domestic heating will be no longer necessary.

Another option for treating wastes, which has not been considered yet is the use of microbial electrolysis cells. This technology is still waiting for application at a real scale. There are several reports regarding the capacity of treating soluble organic components present in a liquid stream, for producing electricity (microbial fuel cell, MFC), producing H_2 gas (microbial electrolysis cell, MEC), or producing valuable organics in the reducing compartment (BES). In the present scenario, BES may be integrated into the biological process for the treatment of organics. Given that this technology is particularly useful for treating soluble components, then a high-solid phase configuration results in inadequate coupling of both technologies.

By considering a solid-state digestion system operating also under batch configuration the application of leachate recirculation along with BES treatment would allow the fast conversion of short-chain fatty acids which accumulate at the initial stage of the reactor. In the present case, an amount of material accumulated during 15 days may be treated in each batch reactor. The initial mixture would have a TS content of 38.1% when prepared following a 50% ratio of food waste and yard waste. To run a solid-state digestion a higher TS content is needed to create a percolating bed, then adding yard trimming rich in lignocellulosic recalcitrant material would allow forming a porous structure but also increases the total volume of the reactor. Here, yard trimmings with a TS content of 70% were assumed, then 35 kg of this material would be needed for mixing with the biodegradable substrate, leading to a reactor volume of 170 L (for a density of 430 kg/m^3 for the bed) which is much higher than the previously considered under high-solid configuration. Along with the reactor, a leachate recirculating tank is needed. If a liquid volume between 30–40% is assumed for the recirculating tank, then a tank with a volume containing 51–68 L is necessary. Although the volume of the reactor here is higher, the total amount of water needed is lower because leachate is recirculated in subsequent batches.

As previously stated, the coupling of BES would allow producing extra energy from the biological degradation of the waste. By considering energy yields reported by Mohanakrishna et al. [45] (0.147–0.322 W/kg COD removed) the amount of electricity produced from volatile fatty acids (VFA) accumulated during digestion can be estimated. Assuming that 5% of volatile solids are transformed into VFA, with a conversion factor of 1.5 g COD/g VS, the amount of electricity annually produced would just account for 205 Wh. If a MEC system is instead considered for producing H_2, then the amount of energy recovered under the same assumptions but in this case using the yield reported by Sun et al. [46] (1.6 mol H_2/mol acetate) would be 16.8 MJ annually.

2.2.3 Scenario 3

There are several reports regarding the installation of small digesters for producing biogas in China and India [47–50]. Many of these installations are dedicated to the treatment of small volumes of waste from single households using simplified designs. However, low biogas production and inefficient operation have been reported. It should also be added that the construction of these decentralized facilities required subsidies to cover installation costs, which otherwise could not be affronted by small farmers [51]. The most common technologies for small-scale digesters in developing countries is the Chinese fixed and flexible dome along with their variations developed in India and Vietnam. The tubular digester is also very popular due to its simplified design. However, the lack of mixing and simplification of the technology makes these systems to be highly demanding in water not making them suitable for African dry countries [52].

Figure 3 shows the main results for this scenario. The amount of daily manure produced considering animal and human feces would account for 252 kg/day. To prepare the digester feed at a TS content of 60 g/L, 237 L/water would need to be available every day. The working volume of the digester would be 39 m^3 which translates into a significant investment for a single family. Therefore, unless financial aid is available, the construction and maintenance of these types of facilities are scarce. The volume of biogas expected from this type of system was estimated by considering an SMP of 180 mL CH4/g VS for the mixture. Thus, the daily volume

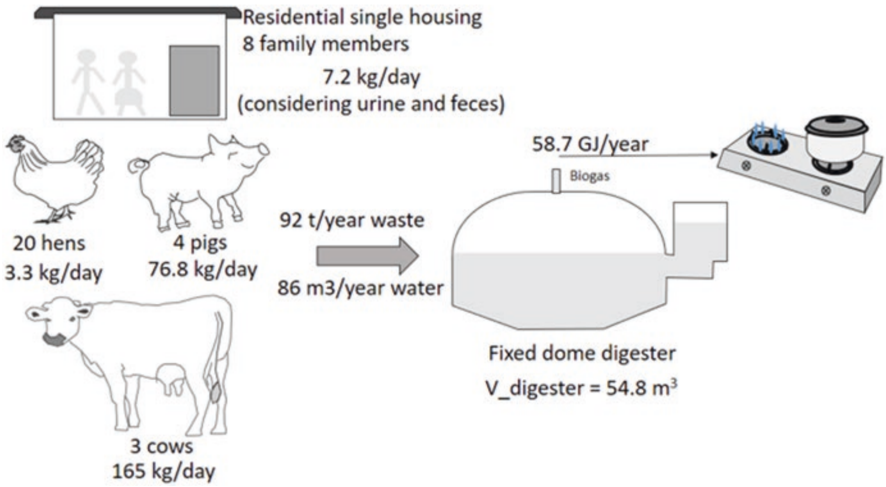

Fig. 3 Main assumptions considered for Scenario 3 evaluating single housing in developing countries under mild climatic conditions

of biogas produced would be 7.5 m^3. This quantity just covers the gas demand for cooking only in the case a gas consumption equivalent to 1.2 m^3/h of natural gas is assumed for 4 h a day.

3 Conclusion

The feasibility of three small-scale digestion scenarios in the residential sector has been studied: residential housing in highly populated areas, single-detached housing and a house with a small farm attached in developing countries. The energy demand cover is 17% in the first case and less than 10% in the second, for the third case, the biogas produced could scarcely cover the gas demand for cooking, if considering no disturbances during the digestion process.

Decentralized anaerobic digestion can contribute to attaining the circular economy model but it does not meet all of the energy requirements of users. This type of configuration may not be suitable in many regions with limited spacing or water scarcity. Therefore, resources must be optimized to obtain the greatest value from residues and take into account the amount of energy necessary for transforming wastes into valuable energetic products.

References

1. Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts—A literature analysis and redefinition. *Thunderbird International Business Review, 60*(5), 771–782.
2. Valero, A., & Valero, A. (2019). Thermodynamic rarity and recyclability of raw materials in the energy transition: The need for an in-spiral economy. *Entropy, 21*, 873.
3. Hobson, K. (2021). The limits of the loops: Critical environmental politics and the circular economy. *Environmental Politics, 30*(1–2), 161–179.
4. Ellacuriaga, M., García-Cascallana, J., & Gómez, X. (2021). Biogas production from organic wastes: Integrating concepts of circular economy. *Fuels, 2*(2), 144–167.
5. Landfill directive. *European Commission, 2008/98/EC*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31999L0031
6. Directive (EU) 2018/851. https://eur-lex.europa.eu/legal-content/ES/TXT/?uri=CELEX%3A32018L0851
7. Malinowski, M., Leon, J. I., & Abu-Rub, H. (2017). Solar photovoltaic and thermal energy systems: Current technology and future trends. *Proceedings of the IEEE, 105*(11), 2132–2146.
8. Ahmad, U. S., Usman, M., Hussain, S., Jahanger, A., & Abrar, M. (2022). Determinants of renewable energy sources in Pakistan: An overview. *Environmental Science and Pollution Research, 29*, 29183–29201.
9. Purohit, P., & Chaturvedi, V. (2018). Biomass pellets for power generation in India: A techno-economic evaluation. *Environmental Science and Pollution Research, 25*(29), 29614–29632.
10. Ibrahim, M. H., Quaik, S., & Ismail, S. A. (2016). An introduction to anaerobic digestion of organic wastes. In *Prospects of organic waste management and the significance of earthworms* (pp. 23–44). Springer.

11. Sevillano, C. A., Pesantes, A. A., Peña Carpio, E., Martínez, E. J., & Gómez, X. (2021). Anaerobic digestion for producing renewable energy—The evolution of this technology in a new uncertain scenario. *Entropy, 23*(2), 145.
12. Ellacuriaga, M., Cascallana, J. G., González, R., & Gómez, X. (2021). High-solid anaerobic digestion: Reviewing strategies for increasing reactor performance. *Environments, 8*(8), 80.
13. Deng, L., Liu, Y., Zheng, D., Wang, L., Pu, X., Song, L., et al. (2017). Application and development of biogas technology for the treatment of waste in China. *Renewable and Sustainable Energy Reviews, 70*, 845–851.
14. Breitenmoser, L., Gross, T., Huesch, R., Rau, J., Dhar, H., Kumar, S., et al. (2019). Anaerobic digestion of biowastes in India: Opportunities, challenges and research needs. *Journal of Environmental Management, 236*, 396–412.
15. Siddiqui, S., Bhatnagar, P., Dhingra, S., Upadhyay, U., & Sreedhar, I. (2021). *Wastewater treatment and energy production by microbial fuel cells* (pp. 1–24). Biomass Conversion and Biorefinery.
16. Jadhav, D. A., Mungray, A. K., Arkatkar, A., & Kumar, S. S. (2021). Recent advancement in scaling-up applications of microbial fuel cells: From reality to practicability. *Sustainable Energy Technologies and Assessments, 45*, 101226.
17. Abdallah, M., Feroz, S., Alani, S., Sayed, E. T., & Shanableh, A. (2019). Continuous and scalable applications of microbial fuel cells: A critical review. *Reviews in Environmental Science and Bio/Technology, 18*(3), 543–578.
18. González, R., Blanco, D., Cascallana, J. G., Carrillo-Peña, D., & Gómez, X. (2021). Anaerobic co-digestion of sheep manure and waste from a potato processing factory: Techno-economic analysis. *Fermentation, 7*(4), 235.
19. Fu, Y., Luo, T., Mei, Z., Li, J., Qiu, K., & Ge, Y. (2019). Dry anaerobic digestion technologies for agricultural straw and acceptability in China. *Sustainability, 10*, 4588.
20. Gómez, X., Cuetos, M. J., Tartakovsky, B., Martínez-Nuñez, M. F., & Moran, A. (2010). A comparison of analytical techniques for evaluating food waste degradation by anaerobic digestion. *Bioprocess and Biosystems Engineering, 33*(4), 427–438.
21. González, R., Rosas, J. G., Blanco, D., Smith, R., Martínez, E. J., Pastor-Bueis, R., & Gómez, X. (2020). Anaerobic digestion of fourth range fruit and vegetable products: Comparison of three different scenarios for its valorisation by life cycle assessment and life cycle costing. *Environmental Monitoring and Assessment, 192*(8), 1–19.
22. Cabbai, V., Ballico, M., Aneggi, E., & Goi, D. (2013). BMP tests of source selected OFMSW to evaluate anaerobic codigestion with sewage sludge. *Waste Management, 33*(7), 1626–1632.
23. Brown, D., & Li, Y. (2013). Solid state anaerobic co-digestion of yard waste and food waste for biogas production. *Bioresource Technology, 127*, 275–280.
24. Antonopoulou, G., Vayenas, D., & Lyberatos, G. (2020). Biogas production from physicochemically pretreated grass lawn waste: Comparison of different process schemes. *Molecules, 25*(2), 296.
25. Zhang, Z., Li, W., Zhang, G., & Xu, G. (2014). Impact of pretreatment on solid state anaerobic digestion of yard waste for biogas production. *World Journal of Microbiology and Biotechnology, 30*(2), 547–554.
26. https://informesweb.idae.es/consumo-usos-residencial/informe.php
27. https://www.idae.es/uploads/documentos/documentos_Informe_SPAHOUSEC_ACC_f68291a3.pdf
28. https://www.statista.com/statistics/933059/per-capita-food-waste-of-selected-countries/
29. https://ecoembesdudasreciclaje.es/cuantos-residuos-produce-una-persona-por-dia/#:~:text=Seg%C3%BAn%20investigaciones%20de%20la%20Universidad,ciudadanos%20en%20la%20Uni%C3%B3n%20Europea
30. https://www.ine.es/ss/Satellite?L=es_ES & c=INESeccion_C & cid=1259950836931 & p=1254735110672 & pagename=ProductosYServicios%2FPYSLayout & param1=PYSDetalleFichaSeccionUA & param3=1259944561392
31. https://www.ine.es/prodyser/espa_cifras/2019/8/

32. https://zerowasteeurope.eu/wp-content/uploads/2020/07/2020_07_06_bic_zwe_report_bio_waste.pdf
33. Eades, P., Kusch-Brandt, S., Heaven, S., & Banks, C. J. (2020). Estimating the generation of garden waste in England and the differences between rural and urban areas. *Resources, 9*(1), 8.
34. Heinonen, J., & Junnila, S. (2014). Residential energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland. *Energy and Buildings, 76*, 295–303.
35. Boldrin, A., & Christensen, T. H. (2010). Seasonal generation and composition of garden waste in Aarhus (Denmark). *Waste Management, 30*(4), 551–557.
36. Cuetos, M. J., Morán, A., Otero, M., & Gómez, X. (2009). Anaerobic co-digestion of poultry blood with OFMSW: FTIR and TG–DTG study of process stabilization. *Environmental Technology, 30*(6), 571–582.
37. Cuetos, M. J., Gómez, X., Martínez, E. J., Fierro, J., & Otero, M. (2013). Feasibility of anaerobic co-digestion of poultry blood with maize residues. *Bioresource Technology, 144*, 513–520.
38. Sánchez, Z., Poggio, D., Castro, L., & Escalante, H. (2021). Simultaneous synergy in CH4 yield and kinetics: Criteria for selecting the best mixtures during co-digestion of wastewater and manure from a bovine slaughterhouse. *Energies, 14*(2), 384.
39. Miramontes-Martínez, L. R., Rivas-García, P., Albalate-Ramírez, A., Botello-Álvarez, J. E., Escamilla-Alvarado, C., Gomez-Gonzalez, R., et al. (2021). Anaerobic co-digestion of fruit and vegetable waste: Synergy and process stability analysis. *Journal of the Air & Waste Management Association, 71*(5), 620–632.
40. Fitamo, T., Boldrin, A., Boe, K., Angelidaki, I., & Scheutz, C. (2016). Co-digestion of food and garden waste with mixed sludge from wastewater treatment in continuously stirred tank reactors. *Bioresource Technology, 206*, 245–254.
41. Landi, M., Sovacool, B. K., & Eidsness, J. (2013). Cooking with gas: Policy lessons from Rwanda's National Domestic Biogas Program (NDBP). *Energy for Sustainable Development, 17*(4), 347–356.
42. Wang, Y., Zhang, J., Sun, Y., Yu, J., Zheng, Z., Li, S., et al. (2020). Effects of intermittent mixing mode on solid state anaerobic digestion of agricultural wastes. *Chemosphere, 248*, 126055.
43. Fierro, J., Martínez, J. E., Rosas, J. G., Blanco, D., & Gómez, X. (2014). Anaerobic codigestion of poultry manure and sewage sludge under solid-phase configuration. *Environmental Progress & Sustainable Energy, 33*(3), 866–872.
44. Zhou, H., & Wen, Z. (2019). Solid-state anaerobic digestion for waste management and biogas production. *Solid State Fermentation*, 147–168.
45. Mohanakrishna, G., Mohan, S. V., & Sarma, P. N. (2010). Bio-electrochemical treatment of distillery wastewater in microbial fuel cell facilitating decolorization and desalination along with power generation. *Journal of Hazardous Materials, 177*(1–3), 487–494.
46. Sun, M., Shenog, G. P., Zhang, L., Xia, C. R., Mu, Z. X., Liu, X. W., Wang, H. L., Yu, H. Q., Qi, R., Yu, T., & Yang, M. (2008). An MEC–MFC coupled system for biohydrogen production from acetate. *Environmental Science Technolgy, 42*(21), 8095–8100.
47. Voegeli, Y., & Zurbrügg, C. (2008). *Decentralised anaerobic digestion of kitchen and market waste in developing countries-'state of the art'in South India*. Proceedings Venice.
48. Abbasi, T., Tauseef, S. M., & Abbasi, S. A. (2012). A brief history of anaerobic digestion and "biogas". In *Biogas energy* (pp. 11–23). Springer.
49. Raha, D., Mahanta, P., & Clarke, M. L. (2014). The implementation of decentralised biogas plants in Assam, NE India: The impact and effectiveness of the National Biogas and Manure Management Programme. *Energy Policy, 68*, 80–91.
50. Luo, T., Khoshnevisan, B., Huang, R., Chen, Q., Mei, Z., Pan, J., & Liu, H. (2020). Analysis of revolution in decentralized biogas facilities caused by transition in Chinese rural areas. *Renewable and Sustainable Energy Reviews, 133*, 110133.
51. Wang, J. (2014). Decentralized biogas technology of anaerobic digestion and farm ecosystem: Opportunities and challenges. *Frontiers in Energy Research, 2*, 10.
52. Mungwe, J. N., Colombo, E., Adani, F., & Schievano, A. (2016). The fixed dome digester: An appropriate design for the context of Sub-Sahara Africa? *Biomass and Bioenergy, 95*, 35–44.

Dried-Fruit Shell Reuse in Green Construction and Building Materials

M. Bellomo, V. R. Margiotta, M. Saeli, S. Colajanni, and T. Campisi

1 Introduction

It is well acknowledged that the building sector, despite its undoubted usefulness, nowadays represents one of the most polluting industrial sectors worldwide, being responsible for the consumption of about 35% of the total energy produced and generating up to 38% of global CO_2 [1].

Having that in mind, there is an urgent need to develop alternative strategies to reduce emissions and the energy consumption, favoring more sustainable energetic approaches. Among the most promising strategies, the circular economy approach (valorization, recycle, and reuse of waste materials/objects/products) resulted in the most viable and effective to reduce natural resources consumption and manufacture greener materials and systems with lower environmental impact [2]. Moreover, the present European regulations tend to establish certain methods of waste management to reduce, recycle, enhance and dispose of the produced waste [3]. In fact, many companies have been converting their materials' manufacturing processes by exploiting wastes from various industrial sectors, undertaking numerous R & D initiatives aimed at identifying local products with characteristics appropriate to such purposes. This has provided a novel set of building materials with a high social and environmental value, carrying on the concept of an economy that perfectly fits with the values of the most modern bio-architecture, supported by the production of novel construction and building bio-materials that are almost exclusively made by organic materials. Therefore, they can be considered as 100% biodegradable.

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Among the waste from agri-food production, biomasses show the greatest potential, being available in large quantities and still being used for the production of alternative energy, biofuels and bio-composite materials. The exploitation of biomass is a priority over its disposal, being a recyclable by-product, with great added value, usable by industries, and capable of diversifying the energy sources, reducing, as a consequence, the dependence on non-renewable resources. Biomass reuse is, in fact, already taking place within the all the industrial sectors, and especially in construction, being used as fuel for the production of cement, paper, ceramics, or for thermal power plants, exploiting agricultural, forestry and urban wastes [4]. In particular, agricultural waste sources, of local provenience, can be innumerable and of various nature. Given the considerable variability, a real estimation of the available residues' annual quantity is not simple and is often subject to huge errors. In fact, clime, crop productivity, and the quantity of waste that is actually usable and not destined for other purposes are all variables that influence the real amount of the annual computation.

Usually, agricultural wastes are left in the field, to obtain a natural fertilizer as a source of nitrogen, or reused in animal husbandry, as a feed additive being rich in fiber, or in other industrial sectors. Furthermore, research shows that agri-industrial residues are often transformed and treated in plants often located far from the industries of origin, generating a rather substantial national wastes movement with high transport costs. All of that makes it rather clear how the reuse of agri-food wastes can provide numerous advantages. More specifically, it would allow to find a valid and convenient alternative to the usual disposal, reducing both the quantity and the costs of transportation, along with the introduction of alternative and biodegradable materials in the market [5]. The most diffuse Italian bio-based agri-food by-products (Fig. 1a-f) can be classified as follows:

- *Cereal straws:* they generally provide to the soil an important contribution of organic substances and their total removal can lead to criticalities due to the lack of storage of organic carbon in the soil itself. Their reuse, as biological resource material, must be well evaluated each time (Fig. 1a).
- *Tree pruning:* currently, only a minimal part is recovered as firewood, as it is usually chopped and buried on-site, or even burned to prevent the spread of pathogens. To facilitate the re-use of this residue for energy purposes, it is first necessary to optimize the waste collection and transport practices (Fig. 1b).

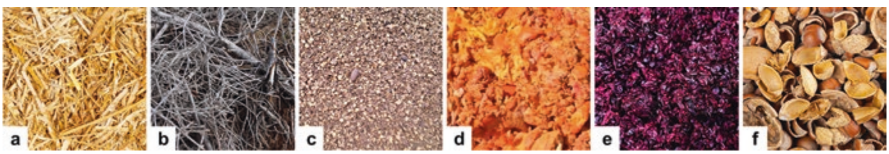

Fig. 1 Main agro-industrial by-products produced in Italy: (**a**) cereal straws; (**b**) tree pruning; (**c**) olive pomace; (**d**) citrus pulp; (**e**) grape-wine pomace; (**f**) dried fruit shells

- *Olive pomace:* nowadays, it shows an almost complete reuse, often in the same oil mills, being used as fuel; separated from the core, reintegrated as pellets, or fermented the peel to obtain biogas (Fig. 1c).
- *Citrus pulp:* obtained from the wastes of lemons and oranges from squeezing, the citrus pulp has various uses, such as fertilizer, feeding livestock or the extraction of pectin (a polysaccharide used in the production of jams). Lately, it has also found use as biomass for the production of electricity (Fig. 1d).
- *Grape-wine pomace:* it is often used in distilleries for the production of alcoholic beverages or in plants for biomaterials generation. Seeds are also used for oil extraction, generally used in cosmetics (Fig. 1e).
- *Dried fruit shells:* they show a relatively short decomposition time and are used in agriculture and gardening as compost or for mulching. In some cases, they are also used as a natural fuel (Fig. 1f).

Therefore, the types and quantities of agricultural wastes that can be reused as biomass are highly numerous and different. Some already find different uses in the manufacture, with a number of available commercial products, while others still struggle to find an effective reuse. An example is the dried fruit shell, being one of the most diffuse wastes in the agri-food production chain and is of such quality that it can be exploited in many industrial sectors, such as construction.

The purpose of this study is, therefore, to discuss the potentials provided by dried fruit wastes (mainly shells), focusing on some of the most widespread types, using the shells as an aggregate for the production of bio-composite materials for construction and building applications, studying both the peculiar characteristics of the individual varieties of selected shells and the researches carried out within the scientific and technical community.

2 The Scale of the Problem: Dried Fruit Bio-Wastes Quantities and Availability

Dried fruit is one of the most cultivated and consumed foods in the world, thanks to the high level of proteins, vitamins, and mineral salts, along with their antioxidant properties. There are different varieties and types of dried fruit that could be basically divided into two main categories: “nuts” (walnuts, hazelnuts, almonds, pistachios, peanuts, chestnuts, etc.) and “pulpy fruit” (apricots, figs, dates, plums, raisins, etc.). During the harvesting and the fruit processing, large quantities of by-products are generated, such as shells or peel, whose disposal can represent either an economic or environmental problem. In Fig. 2a-d some of the most diffuse dried fruit shells are shown. Usually, these wastes are reused in mulching or as fuel pellets, but, more often, they are disposed of by incineration, contributing to the production of greenhouse gases. In particular, the countries where the cultivation of nuts is predominant, both in terms of quantity and variety, are even more affected by this problem, having great quantities of shell waste, which does not find any productive

Fig. 2 Types of dried fruit shells: (**a**) walnut shell; (**b**) hazelnut shell; (**c**) peanut shell; (**d**) almond shell

reuse, if not total disposal. Indeed, dried fruit waste, such as the shells, represents a potential source, currently very little exploited by industries, that should be re-used in the manufacture of eco-sustainable building materials, thanks to the excellent thermal performance and a discrete physical-mechanical properties. Actually, many studies report the development of eco-sustainable materials with a low environmental impact, obtained through the use, in part or in whole, of agri-food wastes generated from dried fruit production. Particularly interesting is the possibility of re-using dried fruit shell waste coupled with polymers in order to produce new bio-composite materials for the construction sector.

Italy is one of the few countries that can boast a centuries-old tradition of dried fruit cultivation, counting a total production of over 300.000 tonnes/year [6], an excellence of the Italian territory still recognized worldwide, both in terms of the offered quality and variety. Among the leading products, there are many specialities such as the Campania hazelnuts, the Venetian walnuts, the Tuscan pine nuts, and the Sicilian pistachios and almonds.

In order to understand the potential and quality offered by dried fruit waste, that can be effectively re-used as aggregate for the production of bio-composite materials for applications in construction, some of the most important types of dried fruit, produced in the world, are here analyzed, focusing on the production, characterization and use, taken from a literature survey, of the single typologies of shell waste dealt with.

2.1 Walnut Shell

Walnut is the fruit of *Juglans regia* L. (Iuglandaceae) with a global production amounting to more than 3.7 million tonnes/year. The main producer is China, with an output of 1.7 million tonnes/year, followed by the USA and Iran [7]. In Italy its production, although widespread throughout the whole peninsula, is particularly low, hovering around 15,000 tonnes/year, most of it from Campania, with an annual production of about 6000 tonnes [6]. The kernel (innermost edible nut part), is rich in polyunsaturated fatty acids (52–70%), protein (12–24%), of which amino acids, and minerals (1.5–2%). It also shows a wide variety of flavonoids, polyphenols, and phenolic acids. The fruit is mainly used in the food industry, both in fresh or in dried form, as an ingredient for various products, such as oil, spirits, and sweets. The hull (peel's fleshy part) is used in paints production, while the shell as fuel pellets. The walnut shell accounts for about 56% of the total fruit weight, suggesting a worldwide generation of about 2.1 million tonnes/year (Fig. 3a). The shells (Fig. 2a) lignocellulosic structure is composed of [8] cellulose (26–35%), hemicellulose (30%), and lignin (27–52%). The main physical-mechanical characteristics are density – 250 kg/m^3, shell thickness – 1.6–1.9 mm, modulus of elasticity – 220 MPa, and calorific value – 4.8 kWh/kg. In the scientific literature, it seems to be a modest interest in the use of walnut waste, often in combination with other agri-food waste or dried fruit shells, and commonly bonded with polymers. This waste is mainly reported to be used as a filler, showing good mechanical properties and good water absorption.

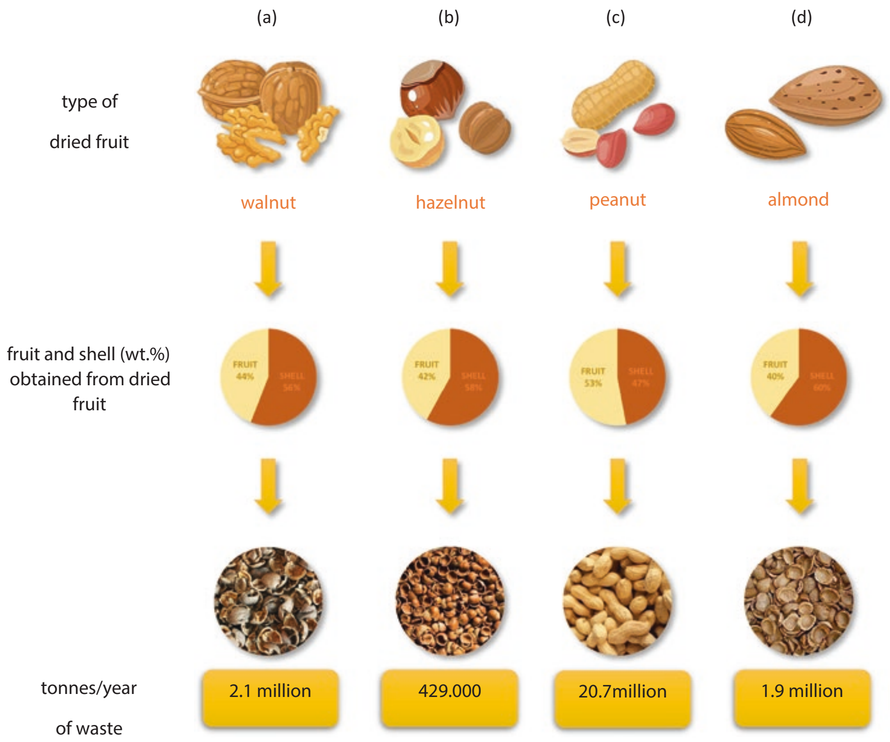

Fig. 3 Percentage by weight of fruit and shell for various types of dried fruit, with the calculated quantity of waste (tonnes/year) of shell waste: (**a**) walnut; (**b**) hazelnut; (**c**) peanut; (**d**) almond

2.2 Hazelnut Shell

Hazelnut is the fruit of the hazelnut tree (*Coryllus avellana*) belonging to the Betulaceae family, native to Anatolia and Greece. More than 740 thousand tonnes/year of hazelnuts are produced worldwide, with Turkey leading the market, supplying more than half of global production, followed by Italy and the USA [9]. In Italy, the hazelnut cultivation shows production of nearly 145,000 tonnes/year. The main suppliers are Campania, Piedmont and Lazio, with production between 30,000–45,000 tonnes/year [6]. The shell is currently used in mulching, as fuel, or in the production of furfural, for dyes. Averagely, the hazelnut shell accounts for about 58% of the total weight of the fruit, suggesting a worldwide production of hazelnut shell waste of about 429,000 tonnes/year (Fig. 3b). The shell (Fig. 2b) is endowed with highly effective bio-absorbent features, capable of absorbing and removing toxic ions such as tri- and hexavalent chromium, cadmium and zinc from aqueous solutions. It has also natural phenolic antioxidants and a great xylan content, which could come in handy if used in the chemical industry [10]. The structure [8] contains cellulose (27–40.5%), hemicellulose (11–30%), and lignin (27–43%). The physical-mechanical properties of the shell are density – 360 kg/m^3, thickness – 1–1.2 mm, modulus of elasticity – 250 MPa, and calorific value – 4.2 kWh/kg. In the literature, there is little interest in the use of hazelnut shell waste, often used together with walnut shell scraps or wood shavings, bonded with polymeric materials. Generally, the hazelnut shell is mainly used as a filler in resins or as a substitute for wood, showing fair mechanical properties and good water absorption capacity.

2.3 Peanut Shell

The peanut derives from the homonymous plant (*Arachis hypogaea*), an annual essence of the Fabaceae family. Worldwide peanut production amounts to over 44 million tonnes/year. The main producer is China, with 16 million tonnes/year, followed by India and Nigeria [11]. In Italy, its cultivation is almost completely absent, with a production of about 45 tonnes/year, mainly concentrated in the northern area, of which 62% is from the Venetian area [6]. Peanut shell accounts for about 47% of the total fruit weight, suggesting a worldwide production of peanut shell waste of about 20.7 million tonnes/year (Fig. 3c). The lignocellulosic structure of the shell (Fig. 2c) [12] is made of cellulose (22%), hemicellulose (24%), and lignin (35%). In literature, the interest in its reuse is quite low, with a preference for wood shavings, bonded with polymers. Usually, peanut shell is mainly used as a filler for resins or wood substitute, showing fair mechanical properties and good water absorption capacity.

2.4 Almond Shell

Almonds are obtained from almond tree (*Prunus dulcis*) belonging to Rosaceae family with a global production accounting for about 3.2 million tonnes/year, 62% in the USA, followed by Spain and Iran [13]. In Italy, its cultivation is widespread throughout the whole peninsula, mainly concentrated in the south, with a total production of about 85,000 tonnes/year. Sicily is the main supplier with 64% of the total production, with the province of Agrigento and Siracusa producing 13,000–15,000 tonnes/year, respectively [6]. The almond industry is currently interested in husks and shells valorization as animal feed or fuel. The husks correspond to about 4–8% of the total weight of the fruit and have useful properties for oxidative processes control in food products, due to its high content of flavonoids and phenolic acid. The shell might find some application in the chemical industry because of the high xylan content [8]. From the literature, the almond shell accounts for about 60% of the total fruit weight, suggesting a worldwide production of waste of about 1.9 million tonnes/year (Fig. 3d). The shell's lignocellulosic structure (Fig. 2d) [8] is made of cellulose (22–51%), hemicellulose (29–32%), and lignin (20–28%). Whereas, the shell's physical-mechanical characteristics are density – 340 kg/m^3, thickness – 1.5–1.8 mm, modulus of elasticity – 280 MPa, and calorific value – 5.2 kWh/kg. In literature, it is reported use as an aggregate, reinforcing agent, or constituent together with various types of polymers or materials of mineral origin [14].

3 Dried-Fruit Shell Reuse for Green Applications in Construction

In this section, we report the state of the art of R & D on the possible materials' development with low environmental impact and cost, obtained through the use, in part or in whole, of agri-food or vegetal waste. Different research criteria were used in order to analyze the scientific publications based on the used binders and for various applications in construction and not (Fig. 4a). From the analyzed data, it is clear that the scientific community is highly interested in the reuse of shell wastes [14]

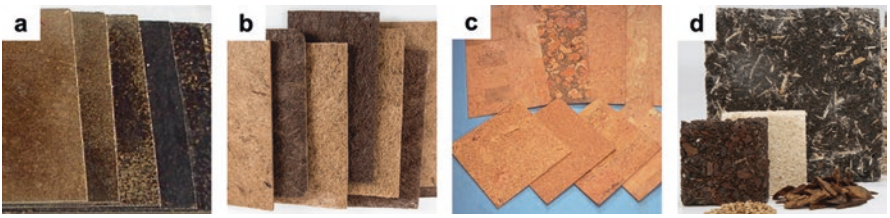

Fig. 4 Example of biowaste-based commercial products: (**a**) panels with almond shells, (**b**) coconut husk fiber panels, (**c**) cork-based panels (**d**) cork and corncobs residue panels

mainly with polymeric binders. The selection of the almond shell is understandable being the most widespread waste globally of this kind, which currently does not find a proper re-use outside the production chain; while, the choice of polymeric materials is associated with their extreme workability, combined with adequate physical and mechanical properties, which, although unable to guarantee structural functions (especially in construction), find multiple uses and applications, as in design or interior furniture. These data also define how there is still a lot of space for research on materials of mineral origin, which, unlike synthetic or polymeric ones, are more eco-sustainable, especially when combined with agricultural production wastes. To simplify the comparison between the various experiments, the analysis of the state of the art was divided by the type of used binder.

3.1 Thermosetting Polymer

Epoxy resin has been largely studied to manufacture bio-composite panels or materials originated by joining thermosetting polymer with nut shells [15], often in addition to natural fibers, for example, coir or straw (Fig. 4b), which slightly improve the material's flexibility [16, 17]. Mechanical tests showed a mechanical strengths decrease often correlated to the amount of reused waste. Clearly, this is related to the shells' physical characteristics, which, compared to resin, show lower strength, thus affecting all the composites properties. In addition, another negative aspect is water absorption which usually tends to increase with waste. Other studies investigated urea-formaldehyde composites, mainly on the production of panels made of a mixture of wood chips and crushed nutshells [18–20] as a replacement for other materials such as cork (Fig. 4c,d). Investigations have shown that the partial substitution of shells for wood reduced the formaldehyde emission of the panels and improved the water absorption and swelling properties of the material, decreasing, however, the mechanical strength, which lowers with the waste quantity. These data are clearly justified by the different content of cellulose and lignin in the nut shells if compared to wood. In fact, cellulose (which is higher in wood) strengthens the material, but promotes the water absorption. In contrast, lignin (which is higher in nut shells) contributes to the waste fragility. Therefore, it decreases the mechanical strength along with the water absorption in proportion to the amount of used waste.

3.2 Thermo-Soft Plastic

Thermoplastic polymers also have been largely investigated showing how their matrices can be used in combination with nut shells or other plant waste (Fig. 5a) to make new bio-composites [21–23]. The results, in general, show a stiffness, hardness, and elastic modulus increase, in relation to the amount of shells; conversely,

Fig. 5 Existing building where biowaste-based products were used: (**a**) gas station in Dinteloord (the Netherlands) that is covered by biobased panels based on bioresin and hemp fiber, (**b**) facades made with panels of road grass, recycled toilet paper and fabrics, (**c**) Flatiron PDX in Portland (USA) whose façade and floor are made with laminated wood panels. (**d**) Danish Wadden Sea Center in Okholmvej (Denmark) whose façade and roof were clad using local straw

an embrittlement is reported, which causes a decrease in elasticity, tensile, and flexural strength. The main cause of this loss, as evidenced by SEM analyses [24], is the poor compatibility between the polymer matrix and the nut shells, which, unable to bond optimally one with each other, tends to break more easily the bonds, generating voids and slumps on the material's surface. In addition, the presence of material buildup, caused by inadequate mix between matrix and waste, causes further deficits to the mechanical strengths. To overcome that, synthetic or natural compatibilizers were used to improve the bond between the shell particles and the matrix. Among those, maleinized linseed oil [25] turned out to be highly effective, both because of its satisfactory results and its ecological qualities, which partly compensate the poor recyclability of the polymers itself.

3.3 Mineral or Natural Binders

Studies on mineral and natural binders [25], including OPC [26, 27], showed a lower strength and greater brittleness of the produced bio-composites, caused by the nut shells. That mainly prevents structural uses, still being suitable for surface coating, which is also guaranteed by the nut shells' low thermal conductivity. In addition, the choice of these bio-composites is still preferable to those derived from polymers, as they are more environmentally friendly and easier to dispose of and recycle (as in the example in (Fig. 5b). Other studies focused on dried fruit shells to manufacture chipboard free of petrochemically artificial binders, by using the hot press method to obtain completely environmentally sustainable products [28, 29] and very similar to the classic wooden cladding panels (Fig. 5c,d). From the analysis of the results, it was found that the use of smaller shell particles positively affects the mechanical properties, redeeming the panels stronger even though stiffer. The resulting products resulted suitable for interior walls or laminated floors, demonstrating how it is technically viable producing shell particleboard panels without the use of artificial binders.

4 Conclusion

To conclude, it is well acknowledged how the extreme need to reduce the environmental impact associated with construction led to the development of novel and innovative organizational and production methodologies, to reduce the present energy and resource consumption. Among the various proposed alternatives, the circular economy approach resulted in one of the most concrete solutions, proposing an economy model based on the valorization and re-use of the produced wastes, which has now become the foundation of the present European regulations. Among the currently unexploited industrial wastes, the agri-food sector seems to offer a huge choice of possibilities. In particular, the dried fruit industry generates tremendously large quantities of shell waste, worldwide. As a direct consequence, the scientific community started to show, in the last decade, a considerably increasing interest in the re-use of such waste for the production of novel bio-composite materials. Those, indeed, offer great potential, and it was largely demonstrated that it is possible to manufacture new components for construction with an extremely low environmental impact. A large number of studies in the field of green building and waste reuse could change the way architecture, and the construction sector in general is perceived nowadays. Precisely for that, R & D on such novel bio-composite waste-based materials needs to be deepened, so as to lower the consumption of non-renewable resources and guarantee a more prosperous future for the future generations.

References

1. 2020 Global status report for buildings and construction, Towards a zero-emissions, efficient and resilient buildings and construction sector.
2. Ilinova, A., & Kuznetsova, E. (2022). CC(U)S initiatives: Prospects and economic efficiency in a circular economy. *Energy Reports, 8*(1), 1295–1301.
3. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
4. Gil, A. (2022). Challenges on waste-to-energy for the valorization of industrial wastes: Electricity, heat and cold, bioliquids and biofuels. *Environmental Nanotechnology, Monitoring & Management, 17*, 100615.
5. Pierro, N., Giocoli, A., Montola, V., & Dipinto, S. (2021). *Valutazione disponibilità biomasse agro-industriali a livello nazionale e loro pubblicazione sul portale webgis atlante delle biomasse*. ENEA.
6. ISTAT Data. (2020). *Production of dried fruit in Italy.*
7. ATLAS BIG. (2018-2020). *World production of walnuts by country*. https://www.atlasbig.com/it/paesi-per-produzione-di-noci
8. Queirós, C. S. G. P., Cardoso, S., Lourenço, A., Ferreira, J., Miranda, I., Lourenço, M. J. V., & Pereira, H. (2020). Characterization of walnut, almond, and pine nut shells regarding chemical composition and extract composition. *Biomass Conversion and Biorefinery, 10*, 175–188.
9. ATLAS BIG. (2018-2020). *World production of hazelnut by country*. https://www.atlasbig.com/it/paesi-per-produzione-di-nocciole

10. Cruz-Lopes, L., Martins, J. M., Esteves, B., & Lemos, L. (2012). *Ecowood 2012 – 5th international conference on environmentally-compatible Forest products*. Fernando Pessoa University, Oporto, Portugal, 5–7 September 2012.
11. ATLAS BIG. (2018-2020). *World production of peanuts by country*. https://www.atlasbig.com/it/paesi-per-produzione-di-arachidi
12. Martin, C., Alriksson, B., Sjöde, A., Nilvebrant, N., & Jönsson, L. J. (2007). Dilute sulfuric acid pretreatment of agricultural and agro-industrial residues for ethanol production. *Applied Biochemistry and Biotechnology, 136–140*, 339–352.
13. ATLAS BIG. (2018–2020). *World production of almond by country*. https://www.atlasbig.com/it/paesi-per-produzione-di-mandorle
14. Bellomo, M., Colajanni, S., Margiotta, V. R., Nicolini, E., Saeli, M., & Mamì, A. (2022). Almond shell reuse: a viable non-conventional aggregate for sustainable building materials. In *ArchDesign'22/IX. International architectural design conference proceedings* (pp. 55–67). Özgür Öztürk Dakam Yayinlari.
15. Ethmane, I. A., & Yahfdhou, A. (2020). Effect of almond shell particles on tensile property of particleboard. *Chemistry & Material Sciences Research Journal, 2*, 51–54.
16. Singh, V. K., Bansal, G., Negi, P., & Bisht, A. (2016). Characterization of flexural and impact strength of jute/almond hybrid biocomposito. *Journal of Testing and Evaluation, 45*, 763–772.
17. Rao, D. K., & Gope, P. C. (2015). Fracture toughness of walnut particles (Juglans regia L.) and coconut fiber-reinforced hybrid biocomposito. *Polymer Composites, 36*, 167–173.
18. Pirayesh, H., Khanjanzadeh, H., & Salari, A. (2013). Effect of using walnut/almond shells on the physical, mechanical properties and formaldehyde emission of particleboard. *Composites Part B: Engineering, 45*, 858–863.
19. Güler, C., Çöpür, Y., & Büyüksari, U. (2009). Producing particleboards from hazelnut (corylusavellana L.) husk and European Black Pine (Pinus nigra Arnold). *Wood Research, 54*, 125–132.
20. Gatani, M. P., Fiorelli, J., Medina, J. C., Arguello, R., Ruiz, A., do Nascimento, M. F., & Savastano, H., Jr. (2013). Technical production viability and properties of particleboard made with peanut husks. *Revista Materia, 18*, 1286–1293.
21. Essabir, H., Nekhlaoui, S., Malha, M., Bensalah, M. O., Arrakhiz, F. Z., & Qaiss, A. (2013). Bio-composites based on polypropylene reinforced with Almond Shells particles: Mechanical and thermal properties. *Materials and Design, 51*, 225–230.
22. Kuram, E. (2020). Rheological, mechanical and morphological properties of hybrid hazelnut (Corylus avellana L.)/walnut (Juglans regia L.) shell flour-filled acrylonitrile butadiene styrene composite. *Journal of Material Cycles and Waste Management, 22*(6), 2107–2117.
23. Nasution, H., Kosasih, K., & Al Fath, M. T. (2020). Properties of unsaturated polyester composite filled with cellulose from peanut shell (Arachis hypogea I.): The effect of filler content and compatibilizer addition. *IOP Conference Series: Materials Science and Engineering, 801*, 012083.
24. Liminana, P., Garcia-Sanoguera, D., Quiles-Carrillo, L., Balart, R., & Montanes, N. (2018). Development and characterization of environmentally friendly composites from poly(butylene succinate) (PBS) and almond shell flour with different compatibilizers. *Composites Part B: Engineering, 144*, 153–162.
25. Soriano, L., Font, A., Tashima, M. M., Monzó, J., Borrachero, M. V., & Payá, J. (2020). One-part blast furnace slag mortars activated with almond-shell biomass ash: A new 100% waste-based material. *Materials Letters, 272*, 127882.
26. Matos, A. M., Ramos, T., & Sousa-Coutinho, J. (2013). Non-conventional additions from agricultural waste. *Sustainable Construction Materials and Technologies, 2013*, e523.
27. Pirayesh, H., & Saadatnia, M. A. (2016). Effects of accelerating agent and SiO2 nano-powder on the mechanical and physical characteristics of nut shell–cement based composites. *Materials and Structures/Materiaux et Constructions, 49*, 3435–3443.

28. Ferrandez-Villena, M., Ferrandez-Garcia, C. E., Ortuño, T. G., Ferrandez-Garcia, A., & Ferrandez-Garcia, M. T. (2019). Study of the utilisation of almond residues for low-cost panels. *Agronomy, 9*, 811.
29. Ferrandez-Villena, M., Ferrandez-Garcia, C. E., Andreu-Rodriguez, J., & Ferrandez-Garcia, M. T. (2013). Effect of pressing conditions on physical and mechanical properties of binderless boards made from almond hulls (Prunus dulcis (Mill.) DA Webb). In *Proceedings of the 41 international symposium on agricultural engineering*, University of Zagreb Faculty of Agriculture, Opatija, Croatia, pp. 392–397.

Functional Hospitals for Humans

Elena Bellini, Nicoletta Setola, and Giuseppe Caserta

1 Introduction

Hospital building design deals with high complexity, related to the configurational layouts, the distribution and the architectural typologies. The hospital community is composed of diverse and complex users: health professionals, patients, caregivers, visitors, etc. Each user generates a different flow by living and experiencing the hospital spaces. Flows and connections have a big impact on the hospital configuration, also affecting the operational costs and the efficiency of the hospital system. The organizational complexity is represented by the activities carried out and the equipment and technological infrastructures involved that constantly change. Hospitals have been dealing with organizational and spatial challenges posed by continuous technical, medical and social developments. The complexity is represented by the effort to respond to these evolutions and maintain high levels of quality over the time. Highly complex healthcare structures need space and management flexibility in the medium and long term by a flexible layout that allows spatial transformations to allocate different functions in the same spaces [3]. On the other hand, new buildings should be designed by using innovative typologies and new configurational and operational models to be resilient.

Innovation in building typologies is going to be developed by the reinterpretation of traditional models into hybrid typologies that combine traditional hospital layouts and configurations to prioritize new principles: humanization, psycho-social recovery and restoration. It is widely recognized that the hospital environment in terms of layout configuration and spatial characteristics has an impact on how

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people move, act and behave in space, as well as on their perception and wellbeing. Research driven design and supporting design tools can define the space requirements to address functional hospitals for "humans" (patients, staff, visitors), taking people into consideration in the design process, since the conception phase.

This research is going to contribute to the knowledge of new models of typologies and flows in hospitals' conception phase by the analysis of international case studies and best practices. How functional requirements are used by designers to face hospital complexity towards humanization?

2 Background

It is well known that the hospital environment has a direct and indirect impact on people [20]. Since the 90's, Evidence Based Design (EBD) aims at making evidence of the therapeutic role of spaces in terms of patients and staff's satisfaction [25]. The concept of "humanization" of hospitals is "a therapeutic practice that encourages the patient's participatory and active role in the therapeutic path and in the social structure of the hospital" [21]. People's well-being can be also quantified by health outcomes, such as: reduction of drug use, pain therapy, hospitalization time, etc. Physical and psychological well-being is also affecting quality of care in terms of healthcare staff productivity and satisfaction: risk of mistakes, burnout decrease, concentration and productivity increase, promotion of the sense of identity and belonging, etc. The holistic approach of humanized and person-centered architecture can emphasize multiple dimensions of health [7]. The environments should be designed in order to provide adequate fulfilment not only to the functional needs, such as accessibility or the distribution of space, but also to the psycho-emotional and social ones, such as the psycho sensory well-being, which is an extension of the needs framework, to which it generally refers [6]. Starting from these concepts, "Functional hospitals for humans" could be defined by the following fundamentals.

2.1 Flows, Layouts, Relations

The network of flows generates the matrix of the hospital layout and affects the hospital configuration. Configurational studies in architecture research deal with the configuration of the spatial layout, the arrangement of spatial elements and their relationship. Since the 1980s, environmental research has been looking for the relationship between layout configuration and human behavior [11]. Evaluation and monitoring tools have been defined for this aim. Connections and flows are strictly related to the healthcare organization and efficiency, but also to the affirmation of public spaces and healing environments as a patients and healthcare professionals' right. Some architectural studies have highlighted the relationship between aspects of the spatial layout and the behavior of users who spend time there in terms of visibility, accessibility and relationality [19]. People live and experience the hospital space, spending time in the public spaces, waiting, resting, developing relations with the other components of the hospital community [22]. The public spaces of a hospital constitute connections between the main entrance and the different functional areas. They serve to welcome everyone who visits the hospital and to guide them towards the visible routes to the different areas and healthcare services, offering adequate areas in which to wait for medical services, resting and regenerating, also by the use of restorative elements [5]. They can provide an enrichment of meaning to spaces and increase the healing value of architecture, highlighting the humanization of all hospital spaces and the centrality of the patient, in terms of well-being, satisfaction and rights.

The management of flows and the organizational layout of hospital functional areas could have a real impact on the environment by the separation of paths and user flows, the wayfinding and ease of orientation, the reduction of distances covered, the relations generated by the design of spaces and the elimination of architectural barriers (physical, mental and sensory).

2.2 Healthy and Health-Promoting Buildings

Architectural design should support the promotion of physical, mental and social health through building design. Hospital environments should be "healthy buildings" and "health promoting buildings".

Healthy Buildings [1] support people's health and well-being through conscious and responsible architectural choices, especially from an environmental point of view. Designing Healthy Buildings means designing green buildings that care for humans, especially vulnerable people, to improve accessibility and health quality. Health Promoting Buildings support "the process that allows people to increase control and to improve their health" (HPH 2021–2025) [12]. Health promotion can be enhanced by designing welcoming spaces, and improving communication and information sharing with patients and the social community on fundamental topics related to health and healthy life, such as healthy food and drinking water, green mobility, relation to nature, physical activity and exercise, etc. Healthy promoting buildings also provide social environments and support by designing public spaces, waiting areas, consulting spaces and green areas, to promote the relations between patients, patients and families/caregivers, patients/families and staff.

2.3 Healing Architecture

Architecture can be defined as "healing" according to varied design approaches: Psychosocially Supportive Design [24], Biophilic Design [17] and Salutogenic Design [9]. Following these approaches, positive factors in the space such as nature, art, colors, relaxing sounds, natural light, familiarity elements, etc. [13] can capture the person's attention and interest through positive feelings and reduce stressful thoughts [4]. Natural environments in particular contain elements that promote renewed attention by providing a sense of being away, fascination, extent and compatibility, to promote survival and therefore positive appraisal [8, 10, 14]. Multisensory encounters with nature in the built environment can greatly contribute to comfort, satisfaction, enjoyment and cognitive performance [15]. In addition, art in healthcare spaces can reduce the patient's sense of isolation and foster positive physiological and emotional responses, especially if it includes natural scenarios, promoting restoration, improving moods and encouraging communication [5].

2.4 Inclusion, Accessibility

All hospitals and healthcare facilities should be completely accessible from a physical and sensory point of view. Accessibility is also related to communication and information sharing, to allow each person to have all information that is useful for accessing health services in an easy and safe way. The environmental design could support this aspect by wayfinding strategies to improve comprehension and orientation inside the hospital, clearly identifying the different areas and functions and how to reach them. Connections and flow optimization also improve the work of the healthcare staff, increasing their productivity and reducing the levels of work-related stress. In addition, Sense-sensitive Design [17] can provide a safe and secure environment for all, especially for people in fragile or critical conditions, with high or low sensory sensitivity, such as elderly people, people with dementia, disabilities, Autism Spectrum Disorders, etc.

2.5 Resilience, Flexibility

Healthcare facilities should be resilient to economic, social and health changes and ensure that the system, services and activities respond to the constantly evolving needs and organizational models. It is necessary to define technological and construction solutions that allow flexibility in order to prolong the useful lifetime of a building [2] and have minimal impact on the building and users, without creating obstacles or inconveniences to healthcare activities [3]. The Open Building approach [16] promotes the ability of a building to be flexible, through layout transformations, changes in services and adapting the environmental characteristics to accommodate users' changing needs. In the last years, the COVID-19 pandemic had a key role in stressing hospitals and healthcare facilities flexibility and resilience capability. Distribution and flow organizational programs have been fundamental in complex healthcare facilities, to prevent infections and reduce virus spread.

3 Case Studies: Methodology

We were looking for case studies in Europe that could be representative of the presented principles. We selected 12 hospitals that have been built since 2010, with a number of beds between 350 and 1100 and an extension between 60.000 and 190.000 mq. We decided not to include children's and specialized hospitals, because they would be difficult to compare, *see* Table 1.

4 Case Studies: Results and Discussion

The analysis of selected case studies has been driven according to the fundamentals of "functional hospital for humans" described above. In any project, the design strategies were addressing the quality of the spaces and humanization to create welcoming and healing environments. In the discussion, we are going to focus on the

Table 1 12 hospital and health centers in Europe

N.	Hospital name	Town, Country	Year of construction	Beds	mq	Floors
1	Hosp. Universitari Sant Joan de Reus	Reus, Terragona, Spain	2010	460	109.000	4+2 und.
2	Hosp. Universitario Rey Juan Carlos	Móstoles, Madrid, Spain	2012	570	94.705	8+2 und.
3	Meander Medisch Centrum	Amersfoort, The Netherlands	2013	600	112.000	8+1 und.
4	New North Zealand Hospital	Hillerod, Denmark	2014	660	124.000	4+1 und.
5	Medisch Spectrum Twente	Twente, The Netherlands	2016	620	78.400	7+1 und.
6	Az Groeninge Hospital	Kortrijik, Belgium	2017	1054	115.280	3+1 und.
7	Hospital Delta	Bruxelles, Belgium	2019	500	104.000	6+2 und.
8	Riviera-Chablais Hospital	Vaud-Valais, Rennaz, Switzerland	2019	350	67.000	4+1 und.
9	Hospital Nova	Jyväskylä, Finland	2020	450	116.000	6+2 und.
10	Campus Hospitalo-Universitaire Saint-Ouen Grand Paris-Nord	Paris, France	u.c.	1167	145.000	6+2 und.
11	Nuovo Policlinico di Milano	Milan, Italy	u.c.	900	170.000	7+2 und.
12	Nuovo Ospedale di Andria	Andria, Italy	u.c.	400	75.000	3+1 und.

first fundamental – “flows, connections, relations” – to understand its impact on the configurational layout and the strategies that have driven the design choices. How functionality and humanization have affected these strategies? How can a flows organization generate resilient hospitals?

4.1 Flows and Accesses as the Matrix of the Project

By the comparison of different case studies, we can outline the separation of different functional areas (emergency and high-intensity areas, outpatient areas, inpatient areas, logistics and facilities) as one of the first strategies to define the configurational layout. In all case studies, there is a strong separation between these functional areas that are connected to each other by the public spaces. Each project has translated this strategy in different ways, developing singular layouts that sometimes differ a lot from each other.

Every hospital presents one or two underground floors for the logistics and facilities; only n. 8 has the service area on the upper floor and on the ground floor; n. 1 on the third floor as a technical separation between the more public area (emergency, high intensity and outpatient areas) and the private one (inpatient wards).

The majority of hospitals present a horizontal separation of functions for floors, as we can see in case studies n. 4, 5, 7, 8, 10: logistics (−1), high intensity and emergency area (0), outpatient area (1), inpatient wards (2 and more). N. 8 presents some differences: the outpatient area is both on the ground floor and the first floor, making a stronger connection with the public space; the high intensity is on the first floor with independent access to the emergency area by an external ramp; the logistic area is also on the ground floor, in the back side of the building, with dedicated access.

The other hospitals have a separation of functions for floors but also by the realization of different blocks or buildings. For example, n. 1 presents the high intensity and emergency area on the ground floor, the outpatient area on the first floor and the inpatient wards on the upper floors, but the functions are located in 6 different wings that are perpendicular to the main “street” of the hospital and each wing is dedicated to a different medical specialty. N. 2 presents an organization in modules: one squared underground base for the logistic area; three blocks on the ground floor, connected by the public space, to separate high intensity from the outpatient area and the diagnostic area; two egg-shape towers on the upper floor dedicated to the inpatient area. N. 3 and n. 9 present the high-intensity and outpatient area on the ground floor separated into different blocks by the central “street”, the main public space of the hospital, and the inpatient area on the upper floors. N. 11 is similar on the ground floor, but presents a separation in functional blocks: the central 3-floors block for the emergency and high-intensity area and the 7-floor blocks at the sides for the inpatient area. N. 12 is also similar on the ground floor but presents a separation for medical specialties in different buildings, connected by the public space. Finally, n. 6 is organized in 5 square buildings pierced by green courtyards: one in the center of the hospital, where there is also the main entrance, and the others connected in each coin of the central squared shape. Each building is connected to the central one by the public space but also presents a separate secondary access and different functions. The central block is dedicated to the high-intensity area and the other blocks are dedicated to the outpatient area on the ground floor and the inpatient area on the upper floors, separated for medical specialties.

As we can see from this first analysis, every hospital has a main entrance on the ground floor and a separate emergency access, related to the high-intensity area. The emergency access is often well outlined by the use of colors or different materials, as in n. 2 where the emergency area is identified by a red facade, instead of the rest of the building facades that are white. In n. 7, there are four entrances, one for each side of the hospital, and the main entrance and the emergency one are opposite and well defined for a better orientation. The other two access are dedicated to different medical specialties and some different colors are supporting the wayfinding, highlighting different functions. N. 8 has also 4 strongly separated accesses: the main entrance for visitors is on the ground floor, well identified by the only opening in the facade, acceding to a big courtyard that filters the outside from the inside of the hospital; on the same floor the logistic access in the opposite part of the building and the staff entrance in one lateral side of the rectangular shape; the emergency entrance, as already mentioned, is on the first floor, connected by a ramp. N. 6 is also interesting as it presents a main access in the central block, well separated by the emergency entrance that is located on a different side of the squared building, where it is placed the high-intensity area. The system of flows and connections is developing from this central public area to sort the different functions in the varied blocks. The intersection of each independent block to the central one is characterized by the system of vertical connections and it presents a specific color and a huge graphic with a letter to support wayfinding and a small courtyard to let natural light enter and support visibility. The flows develop in each building around the green courtyards, but the corridor is interior to permit the hospital rooms to look out the greenery. In n. 4, the main access and emergency one are also separated and they are located on two different floors by modelling the soil to have the public entrance on the ground floor, where is placed the outpatient area, and a ramp to connect to the emergency area on the basement floor.

From the main entrance, the hospital flows develop generating different layouts and configurations. From the analysis of these case studies, we can outline 3 main typologies: the “hospital street”, the “village” and the “central plan”.

The “hospital street” is the most common typology we can identify. It is characterized by a linear development of one main connection in correspondence to the main access: the “street”. It also represents the public area of the hospital and all the main social functions develop along this space. To make some examples, we can find this typology in n. 1, 2 (only on the ground floor, in the most public area), 9, 10 (with a big public square at the entrance, to support the relations in the hospital community) and 11 (only on the ground floor, in the most public area, developing a large central hall and two main connections with the opposite high intensity and outpatient area). N. 10 gives the opportunity to analyze the typology of “hospital street” from a different point of view. It represents a very good practice for providing adaptability. The configurational layout has been generated by user flows in the hospital, allowing for independent flows – access/exit, clean/waste – and the possibility to isolate parts of the building. The project has been developed since the Covid pandemic was spreading, generating different requirements. The main flows of the hospital are in the central "street" but present two paths to separate clearly clean and waste. From the street, each module has access and it is developed around a courtyard with a 5 sections composition that makes it possible to diversify the entrance flow to the exit one. Each module has also dedicated vertical connections that make it possible to isolate completely each block in case of necessity.

The "village" is also a development of the hospital street, making a composition of buildings (similar to a village) with a main avenue and public squares from which all "houses" of the hospital can be accessed. N. 3 is an example of this typology. In this case, the public area on the ground floor has a great importance, developing some glass-covered "squares": a winter garden and two secondary big atriums between the wings of the outpatient area, where the vertical connections are well outlined. On the upper floors, the buildings separate into independent blocks for different functions and are connected by suspended walkways. Also in n. 12, there are independent buildings, but they are connected by central flows that develop linearly along green courtyards, where it is also possible to find vertical connections.

The "centric plan" presents a central core that is usually dedicated to the public area with the main access and the vertical connections placed in the center of the hospital building, generating different and singular shapes. This typology is developed in n. 2 (on the inpatient floors), 4, 6 and 7, *see* Fig. 1.

4.2 Greenery and Art as Generators of the Project

From this analysis, we can highlight that the use of greenery is often generating the matrix of the hospital and driving the development of paths and connections. As we can see from the examples, the use of green courtyards is very common to gain natural light and improve air circulation and make people view and experience nature directly. In n. 1, the inpatient wings are connected by the green space that is placed in between each two wings to give the opportunity to the hospital room to look out at nature. In n. 2, the green courtyards are generating the egg-shaped inpatient towers, where the paths develop around the internal public and green space and the hospital rooms gain privacy, also by the use of a double sheet glass and perforated metal facade. The facade is composed of cast glass pieces with a white silkscreen print that creates an interesting effect of distortion to allow the view of the green roof from the room but hide the interior view. In n. 4, the greenery is generating the building layout that is developed around the central green area to offer natural views from each hospital room.

The green area represents the roof of the basement, where natural light and greenery are entering through many courtyards. In n. 6, as already mentioned, the

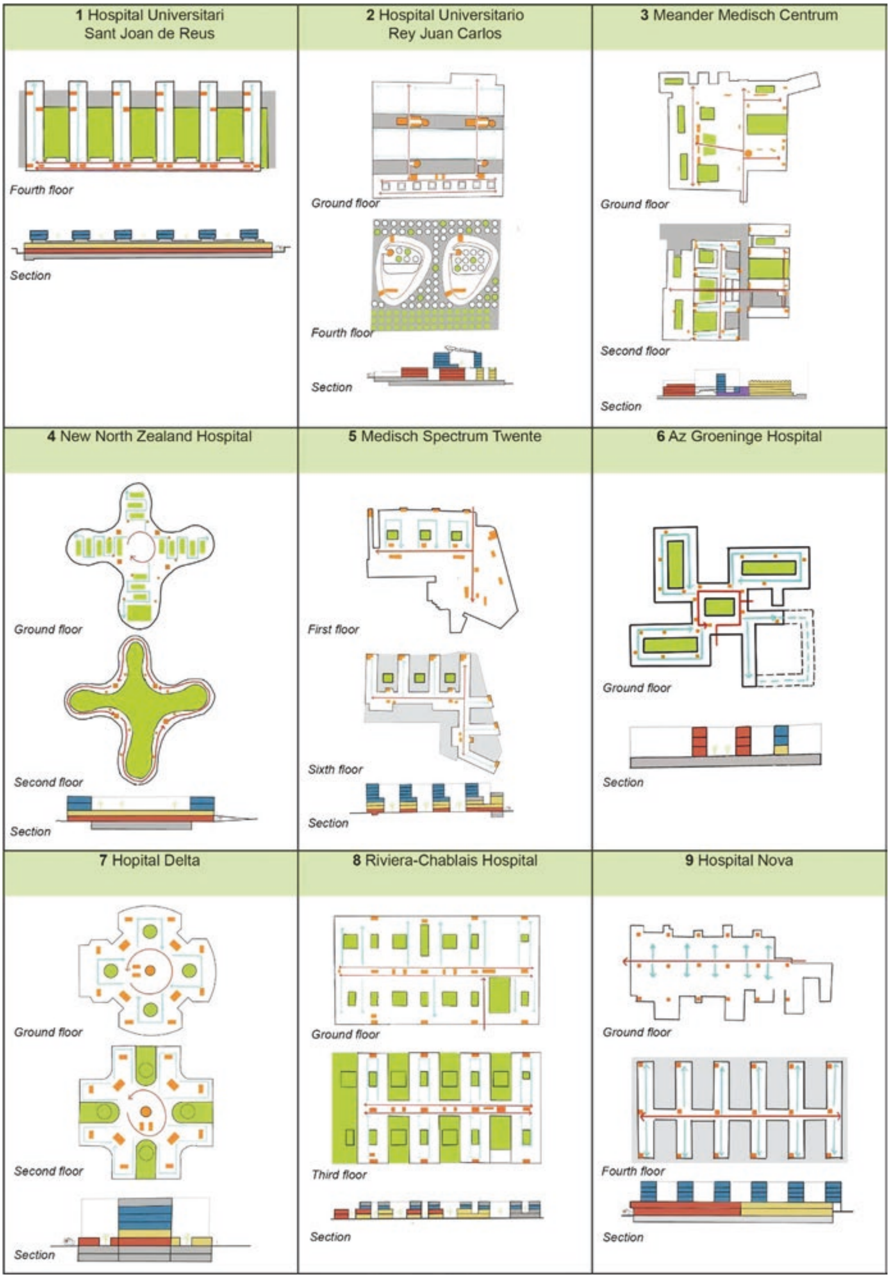

Fig. 1 Features and illustrations in the design of the 12 hospitals and health centers

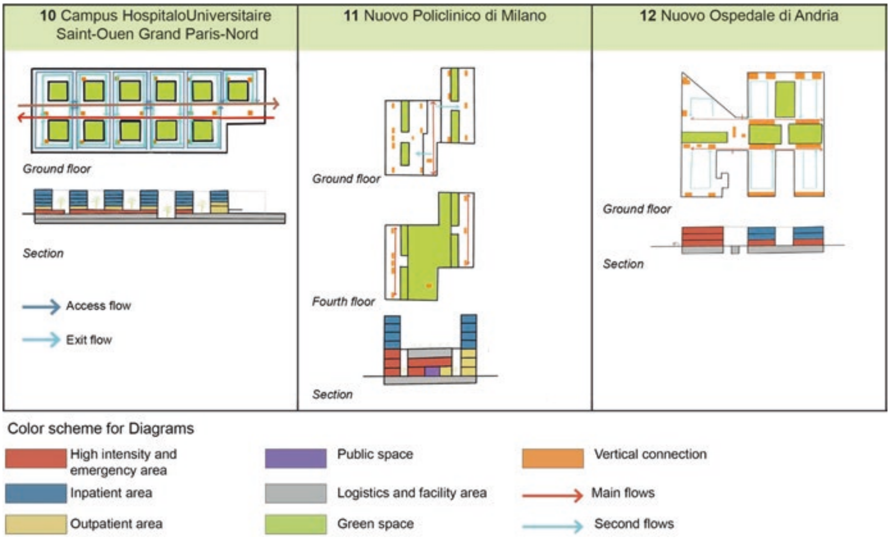

Fig. 1 (continued)

buildings have been developed around the green courtyards. The layout of n. 8 and n. 10 is also generated by the greenery, presenting a mono-block that is pierced by green courtyards that allow natural light and air to enter. For both hospitals, the flows are interior and are not facing the courtyards, where all the medical facilities are opening. In n. 8, on the upper floors, dedicated to the inpatient area, the block is changing from the rectangular mono-block shape to wings and the green space becomes bigger, making nature entering inside the hospital and giving a green view to each room. N. 10 was also characterized by an environmental study of green species, to change and be present in every season of the year. The greenery is also spread on the roof with a big park where all the hospital community can go and rest. In the same way, n. 11 is offering a rooftop garden with many therapeutic activities for patients and visitors: resting and relaxing, socializing, gardening, playing, enjoying time with pets, etc. All the rooms look out at the central garden, developing on the upper floors of the lateral buildings.

Courtyards also improve relations in the hospital community, generating a public space where people can stay, rest and meet. In some cases, these areas are also dedicated to art (n. 5 and 9), an important factor of the healing process, as previously mentioned. In n. 9, the layout is generated by the system of covered courtyards to make natural light entering into the mono-block hospital and make people relax in a colorful and pleasant environment, where many sit and art installations were placed. The courtyards are generators of flows, as the paths are facing the courtyards and the colorful stairs are standing in the art place on the ground floor. It also supports wayfinding, creating a clear environment to support people in the navigation.

5 Conclusion

All these examples are showing how the hospital layouts are generated by functional aspects, such as the separation of functional areas and the optimization of connections between them, but also humanization factors, such as the green and art access as fundamentals of the healing process. These humanizing factors become generators of the design, developing creativity and innovation in shapes and typologies. As we could see from the analyzed case studies, new hybrid typologies were generated by the reinterpretation of traditional and institutional ones such as the hospital street, the mono-block, the geocentric plan, etc. [18, 23, 26]. As an example, we can emphasize this evolution in n. 4, in which the view and the access to greenery, the dialogue with the landscape and the context, the configuration of flows on different floors for diverse users and the optimization of connections, have generated a singular shape. It is a reinterpretation of a geocentric plan, modelling a squared block and piercing the volume by green spaces and courtyards. The result is an organic shape with short internal connections, integrated into the landscape, surrounded by a forest park and enhanced by a green core represented by the large central rooftop garden. In a different way, n. 10 is a beautiful example in which functionality and humanity are strictly related. In this case, resilience and adaptability prevail. In recent years, after the Covdi-19 pandemic, it has become more and more important to be efficient and flexible to big changes over time. New hospital construction should consider these new requirements by the first phase of the design process. At the same time, the health emergency should not affect the humanization of the healthcare facilities, not forgetting the importance of relations and restoration in the healing process.

References

1. Allen, J. G., et al. (2017). *The 9 foundations of a healthy building*. Harvard T.H. Chan School of Public Health.
2. Askar, R., et al. (2021). Adaptability of buildings: A critical review on the concept evolution. *Applied Sciences, 11*, 4483.
3. Astley, P., et al. (2015). Adattabilità operativa e progettuale nelle strutture sanitarie. *TECHNE: Journal of Technology for Architecture & Environment, 9*, 162–170.
4. Awtuch, A. & Gbczyska-Janowicz, A. (2017). IOP Conference Series: Materials Science and Engineering, 245, 042037.
5. Bellini, E., & Setola, N. (2019). The humanisation of hospital spaces: The role of art and architecture. In E. Diana et al. (Eds.), *Art, identity and care. The public spaces of Santa Maria Nuova Hospital* (pp. 57–66). Biblioteca di Medicina e Storia. Quaderni/7. Polistampa, Firenze.
6. Del Nord, R. (2015). L'umanizzazione degli spazi di cura: una ricerca svolta per il Ministero della Salute italiano. *TECHNE: Journal of Technology for Architecture & Environment, 9*, 224–229.

7. Dilani, A. (2008). Psychosocially supportive design: A Salutogenic approach to the Design of the Physical Environment. In *SHB2009-1st international conference on sustainable healthy buildings, Seoul,* pp. 55–65.
8. Gillis, K., & Gatersleben, B. (2015). A review of psychological literature on the health and wellbeing benefits of biophilic design. *Buildings, 2015*(5), 948–963.
9. Golembiewski, J. A. (2017). Salutogenic architecture in healthcare settings. In M. B. Mittelmark et al. (Eds.), *The handbook of Salutogenesis, chap. 26*. Springer.
10. Hartig, T., et al. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology, 23*, 109–123.
11. Hillier, B., & Hanson, J. (1984). *The social logic of space*. Cambridge University Press.
12. HPH. (2020). *Global HPH strategy 2021–2025*. Hamburg.
13. Iyendo, T. O., & Alibaba, H. Z. (2014). Enhancing the hospital healing environment through art and day-lighting for user's therapeutic process. *International Journal of Arts and Commerce, 3*(9), 101–119.
14. Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge University Press.
15. Kellert, R. F., & Calabrese, E. S. (2015). *The practice of Biophilic design*.
16. Kendall, S. H., et al. (2012). *Healthcare facilities design for flexibility: A report on research for the National Institute of Building Sciences*.
17. Mazuch, R. (2017). Salutogenic and Biophilic design as therapeutic approaches to sustainable architecture. *Architectural Design, 87*(2), 42–47.
18. Murphy, M. P., & Mansfield, J. (2021). *The architecture of health: Hospital design and the construction of dignity*. Cooper-Hewitt Museum.
19. Setola, N., & Borgianni, S. (2016). *Designing public spaces in hospitals*. Routledge – Taylor and Francis Inc.
20. Setola, N., et al. (2019). The impact of the physical environment on intrapartum maternity care: Identification of eight crucial building spaces. *HERD, 12*, 67–98.
21. Spinelli, F., et al. (1994). *Lo spazio terapeutico. Un metodo per il progetto di umanizzazione degli spazi ospedalieri*. Alinea Editrice.
22. Strojny, R. (2022). Specificity of general zones in large modern European multispeciality hospitals – Selected case studies. *Budownictwo i Architektura, 21*(2), 031–046.
23. Torricelli, M. C. (2006). Tipologie Edilizie ed Architettura degli Ospedali. In F. Terranova (Ed.), *Edilizia per la Sanità* (pp. 88–111). Utet.
24. Ulrich, R. S., et al. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*, 201–230.
25. Ulrich, R. S., et al. (2008). *A review of the research literature on evidence-based healthcare design*. Healthcare Leadership.
26. Wagenaar, C. (2018). *Hospital: a design manual*. Birkäuser.

Part V
Processes: Methods, Policies and Education for Inclusive Co-planning and Co-design

Artificial Cellulase-Type Catalysts for Depolymerization of Cellulosic Biomass

Ananda S. Amarasekara

1 Introduction

The development of science and technologies for efficient conversion of renewable lignocellulosic biomass to renewable fuels has become one of the high-priority research areas of the day due to the rapid decline of fossil fuel resources and global climate change concerns. Cellulose is the most abundant biopolymer on earth and the resourceful utilization of cellulose is a paramount factor in a sustainable carbon-based future [1, 2]. The complex structure of cellulose is composed of stiff polymeric molecular chains with close packing via numerous strong, inter and intra-molecular hydrogen bonding, making it extremely difficult for solvent molecules to penetrate the structure. As a result of this molecular architecture, it is hard to dissolve cellulose in water and in most common organic solvents [3–5]. This property causes difficulties in improving the processability, fusibility, functionality and hydrolysis of cellulose. Cellulose hydrolysis using dilute aqueous sulfuric acid at high temperature and pressure was the classical method used in the cellulosic ethanol plants in the 1940s [1]. However, the main disadvantage in dilute acid hydrolysis is the poor sugar yields and as a result low ethanol yield; the other disadvantage is the high energy cost associated with operating at temperatures above 200 °C and at high pressures. With the rapid development of enzyme technologies in the last two decades, the acid hydrolysis process has gradually been replaced by enzymatic hydrolysis [6]. Nevertheless, an energy-consuming pre-treatment of the feedstock is required in the enzymatic method and the cost of currently available enzyme preparations is also a major hurdle in the economical production of cellulosic ethanol and large scale implementation of other cellulose based industrial

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processes that require depolymerization of cellulose. Therefore, the development of an energy efficient, recyclable catalytic process for the hydrolysis of cellulose is a very attractive proposition.

2 Acidic Ionic Liquids as Catalysts for Cellulose Hydrolysis

Since the 2002 report on the use of room temperature ionic liquids (ILs) for the dissolution of cellulose, considerable efforts have been devoted to improve the solubility of cellulose in ILs and to use ILs as solvents for processing cellulosic biomass [7, 8]. The first application of ILs for hydrolysis of cellulose was reported by Zhao et al. in 2007 [9, 10]. In this lead study, Zhao et al. showed that cellulose could be hydrolyzed by adding a catalytic amount of sulfuric acid to the cellulose-IL solution and found that cellulose-^{n}-butylmethylimidazolium chloride ($[C_4mim]^+Cl^-$) solution with H_2SO_4/cellulose mass ratio of 0.92 produces total reducing sugars (TRS) and glucose in 59% and 36% yields respectively, within 3 min. Further reducing the acid/cellulose mass ratio to 0.46 produced higher yields after 42 min, and when the mass ratio was dropped to 0.11, the yields of TRS and glucose reached 77% and 43%, respectively, in 9 h [9, 10].

In 2009, our research group first introduced the use of acidic ionic liquids with a sulfonic acid group tethered to the ionic liquid core for the hydrolysis of cellulose [11]. These Brönsted acidic ionic liquids (BAILs) like 1-(3-propylsulfonic)-3-methylimidazolium chloride have the advantage that no separate acid is required as the acid group is built-in to the ionic liquid structure. The unique structural design of BAILs can promote cellulose hydrolysis as the active -SO_3H group is in close proximity to the carbohydrate-binding ionic liquid core. This facile transfer of H^+ from -SO_3H to glycosidic oxygen for the protonation may promote hydrolysis under mild conditions [12]. During these experiments we have shown that cellulose dissolves in BAIL like 1-(3-propylsulfonic)-3-methylimidazolium chloride up to 20% (w/w) in ~2 min by simple mixing with a spatula at room temperature, and this is the highest cellulose dissolution capacity reported to date [11]. Microscope images of rapid dissolution of cellulose in acidic ionic liquid 1-(3-propylsulfonic)-3-methylimidazolium chloride at room temperature and atmospheric pressure is shown in Fig. 1. More importantly, the cellulose dissolved in 1-(3-propylsulfonic)-3-methylimidazolium chloride or 1-(4-butylsulfonic)-3-methylimidazolium chloride could be hydrolyzed at 70 °C under atmospheric pressure by the addition of 2.0 equivalents of water per glucose unit to give glucose along with other reducing sugars. During these experiments, hydrolysis of cellulose (DP ~ 450) in 1-(3-propylsulfonic)-3-methylimidazolium chloride produced the highest total reducing sugar (62%) and glucose (14%) yields, and was attained with 1 h of preheating at 70 °C and 30 min heating at 70 °C, after adding water [11].

In the next stage of research, we found that these acidic ionic liquids can be used as homogeneous catalysts in the aqueous phase as well [13]. For example, a dilute aqueous solution of 0.0321 mol H^+/L 1-(3-propylsulfonic)-3-methylimidazolium

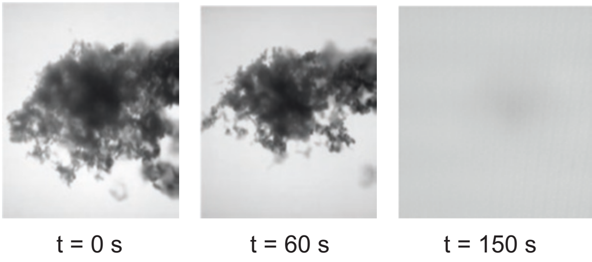


Fig. 1 Microscopic images (x 200) of rapid dissolution of cellulose (DP ~ 450) in acidic ionic liquid 1-(1-propylsulfonic)-3-methylimidazolium chloride. (Amarasekara and Owereh [11]. Copyright: American Chemical Society 2009)

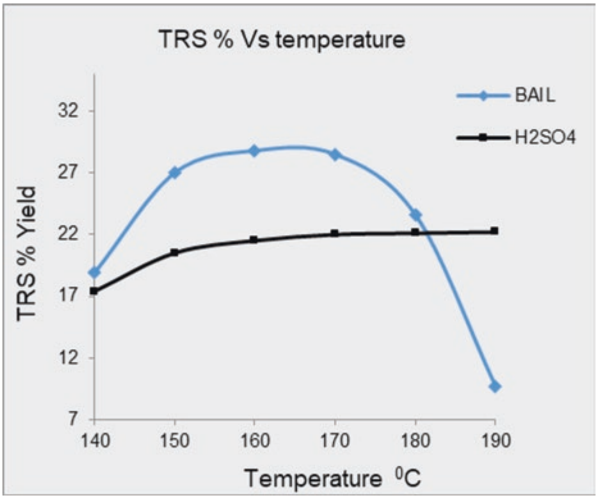


Fig. 2 Changes in the % yields of total reducing sugars (TRS) produced during the hydrolysis of cellulose (DP ~ 450) in aq. 1-(3-propylsulfonic)-3-methylimidazolium chloride (BAIL), aq. sulfuric acid at different temperatures. Acid solutions are 0.0321 mol H^+/L, reaction time = 3.0 h. (Amarasekara and Wiredu [13], Copyright: American Chemical Society 2011)

chloride was shown to be a better catalyst than aqueous sulfuric acid of the same H^+ ion concentration for the hydrolysis of cellulose in water at 140–180 °C temperature range [13]. The changes in the yields of total reducing sugars (TRS) produced during the hydrolysis of cellulose (DP ~ 450) in aqueous 1-(3-propylsulfonic)-3-methylimidazolium chloride and sulfuric acid at different temperatures are shown in Fig. 2. For example, cellulose (DP ~ 450) in aqueous solutions of 1-(3-propylsulfonic)-3-methylimidazolium chloride, and sulfuric acid of the same acid strength (0.0321 mol H+ ion/L) produced TRS yields of 28.5%, and 22.0%, respectively, after heating at 170 °C for 3.0 h. In the same set of experiments, glucose yields of 22.2%, and 16.2% were attained in 1-(3-propylsulfonic)-3-methylimidazolium chloride, and sulfuric acid mediums, respectively. This superior catalytic activity of the BAIL 1-(3-propylsulfonic)-3-methylimidazolium chloride, when compared to sulfuric acid, was explained as a result of an interaction or binding of the imidazolium chloride ionic moiety on the cellulose surface, which assisted the approach of the -SO_3H functionality for the hydrolysis of the glycosidic link in the polysaccharide.

As we have shown in the previous studies that BAILs can operate as cellulase enzyme mimics in the hydrolysis of the biomass model compound cellulose, we have extended the experiments to untreated biomass forms as well [14]. In one study, switchgrass biomass samples collected at three different stages of maturity were tested. These samples degraded into reducing sugars and glucose when exposed to 1-(alkylsulfonic)-3methylimidazolium BAILs under thermal and microwave conditions. The highest reducing sugar (58.1 ± 2.1%) and glucose(15.3 ± 0.5%) yields were obtained for switchgrass samples dissolved in 1-(4-butylsulfonic)-3-methylimidazolium chloride ionic liquid by heating at 70 °C for 1 h followed by treatment with 0.22 g water/g switchgrass and then heating at 70 °C for 1 h for the hydrolysis of polysaccharides. The samples treated under microwave conditions produced relatively lower yields of reducing sugar (22.0 ± 1.5–37.2 ± 1.8%) and glucose (8.0 ± 0.2–12.8 ± 0.4%) yields, compared to heat-treated samples [14].

3 Immobilization of Acidic Ionic Liquid Catalysts

Heterogeneous catalysts are more practical in larger-scale processes due to the fact that they are easy to separate from the product and reactants than homogeneous catalysts. In continuation of our work, we have studied the immobilization of BAIL catalysts on solid surfaces and the application of these heterogeneous BAIL catalysts as well [15]. In this example, a sulfonic acid functionalized acidic ionic liquid modified silica catalyst was prepared in 68% overall yield from 3-chloropropyl silica by a simple two step method involving the nucleophilic substitution of chlorine with imidazole, then condensation with 1,3-propanesultone and acidification using HCl as shown in Fig. 3. This silica-supported acid catalyst was shown to be effective in the hydrolysis of cellulose (DP ~ 450) dissolved in 1-*n*-butyl-3-methylimidazolium chloride at 70 °C, producing glucose and total reducing sugars in 26 and 67% yields respectively [16].

In another example, a BAIL catalyst with a sulfonic acid group tethered to imidazolium cation and immobilized on polystyrene was prepared by a two-step method

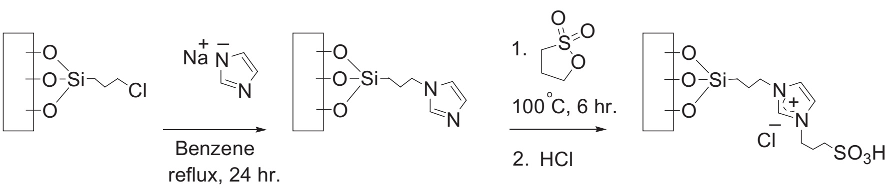
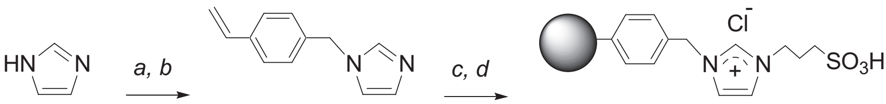


Fig. 3 Synthesis of sulfonic acid functionalized BAIL grafted silica catalyst



a = NaOH, DMSO; *b* = 4-vinylbenzyl chloride; *c* = divinylbenzene, benzoyl peroxide; *d* = 1,3-propane sultone, then HCl

Fig. 4 Synthesis of a polymer-immobilized BAIL catalyst

with 83% overall yield as shown in Fig. 4. This immobilized BAIL catalyst was shown to be a significantly better catalyst than H^+ form of Dowex-50X8 of similar -SO_3H group loading for hydrolysis of untreated Sigmacell cellulose (DP ~ 450) in water under hydrothermal conditions. For example, cellulose hydrolyzed with immobilized BAIL catalyst produced 50.1% yield of total reducing sugars (TRS) after 3 h, at 160 °C, whereas the sample heated with Dowex-50X8 produced only 9.2% TRS yield under identical conditions. Similarly, cellulose hydrolysis using an immobilized ionic liquid catalyst produced a maximum glucose yield of 21.7% after 3 h, at 160 °C, while the maximum glucose yield with Dowex-50X8 catalyst was 4.5%, which was achieved after 3 h, at 170 °C. This enhancement in catalytic activity is explained as a result of an interaction between cellulose and immobilized imidazolium ionic liquid structure with chloride anion [17].

4 Conclusion

The development of BAILs in cellulose hydrolysis catalysts is an important milestone in the search for an efficient and economical process for the production of biofuels and renewable feedstocks from abundant biomass. The introduction of sulfonic acid group functionalized BAILs in the depolymerization of cellulose in 2009 has opened a new branch of research with vast potential and industrial applications. The future of BAILs as biomass processing catalysis is bright, with the possibility of the development of a small molecule mimic for cellulase enzyme. The BAIL has the features of the enzyme; it can bind with cellulose via hydrogen bonds, if the orientation is correct it can deliver the acidic proton to the glycosidic bond of cellulose promoting hydrolysis like the cellulase enzyme. However, more work is needed in the area of binding mechanisms using experimental and theoretical tools.

References

1. Amarasekara, A. S. (2013). *Handbook of cellulosic ethanol*. John Wiley & Sons.
2. Balat, M., & Balat, H. (2009). Recent trends in global production and utilization of bio-ethanol fuel. *Applied Energy, 86*, 2273–2282.

3. Kircher, M. (2015). Sustainability of biofuels and renewable chemicals production from biomass. *Current Opinion in Chemical Biology, 29*, 26–31.
4. Singhvi, M. S., Chaudhari, S., & Gokhale, D. V. (2014). Lignocellulose processing: A current challenge. *RSC Advances, 4*, 8271–8277.
5. Watt, G. D. (2014). A new future for carbohydrate fuel cells. *Renewable Energy, 72*, 99–104.
6. Wyman, C. E. (2008). Cellulosic ethanol: a unique sustainable liquid transportation fuel. *MRS Bulletin, 33*, 381–383.
7. Swatloski, R. P., Spear, S. K., Holbrey, J. D., & Rogers, R. D. (2002). Dissolution of cellose with ionic liquids. *Journal of the American Chemical Society, 124*, 4974–4975.
8. Rogers, R. D., & Voth, G. A. (2007). Ionic Liquids. *Accounts of Chemical Research, 40*, 1077–1078.
9. Li, C., & Zhao, Z. K. (2007). Efficient acid-catalyzed hydrolysis of cellulose in ionic liquid. *Advanced Synthesis and Catalysis, 349*, 1847–1850.
10. Li, C., Wang, Q., & Zhao, Z. K. (2008). Acid in ionic liquid: An efficient system for hydrolysis of lignocellulose. *Green Chemistry, 10*, 177–182.
11. Amarasekara, A. S., & Owereh, O. S. (2009). Hydrolysis and decomposition of cellulose in brönsted acidic ionic liquids under mild conditions. *Industrial and Engineering Chemistry Research, 48*, 10152–10155.
12. Amarasekara, A. S. (2016). Acidic Ionic Liquids. *Chemical Reviews, 116*, 6133–6183.
13. Amarasekara, A. S., & Wiredu, B. (2011). Degradation of cellulose in dilute aqueous solutions of acidic ionic liquid 1-(1-propylsulfonic)-3-methylimidazolium chloride, and p-toluenesulfonic acid at moderate temperatures and pressures. *Industrial and Engineering Chemistry Research, 50*, 12276–12280.
14. Amarasekara, A. S., & Shanbhag, P. (2013). Degradation of untreated switchgrass biomass into reducing sugars in 1-(alkylsulfonic)-3-methylimidazolium Broensted acidic ionic liquid medium under mild conditions. *Bioenergy Research, 6*, 719–724.
15. Wiredu, B., & Amarasekara, A. S. (2014). Synthesis of a silica-immobilized Broensted acidic ionic liquid catalyst and hydrolysis of cellulose in water under mild conditions. *Catalysis Communications, 48*, 41–44.
16. Amarasekara, A. S., & Owereh, O. S. (2010). Synthesis of a sulfonic acid functionalized acidic ionic liquid modified silica catalyst and applications in the hydrolysis of cellulose. *Catalysis Communications, 11*, 1072–1075.
17. Amarasekara, A. S., & Wiredu, B. (2013). Synthesis of an immobilized Bronsted acidic ionic liquid catalyst and hydrolysis of cellulose in water under mild conditions. *Current Catalysis, 2*, 219–224.

Learning from Collaborative Processes to Design the Urban Green Transition

Rossella Roversi, Francesca Sabatini, Serena Orlandi, and Andrea Boeri

1 Introduction

The discourse over participatory practices in urban processes is far from new: in the 1960s the writings of Jane Jacobs testified for a plural and collaborative way of "building and dwelling" cities [1], as opposed to the rationalist attempts to delegate to planning authorities the acts of organizing urban spaces and, by so doing, regulating urban life. Europe has been at the forefront of both research and practice of participation, building upon the post-war ethos of solidarity and cooperation among states [2] and a historically grounded political democratic culture [3], even more strongly perceived in Mediterranean Europe.

A Mediterranean discourse over participation can be established for a threefold reason: first, it is possible to identify, at least for some countries, a distinctive Mediterranean welfare regime, "not only because of […] geographic proximity but also due to common historical and cultural legacies" [4]. Second, because of the underlying collectivist culture characterizing its socio-anthropological scenario [5]. Third, the informality underlying the social economy of Mediterranean cities has made it possible for many grassroots movements to emerge [6] such as vernacular adaptive reuse, circuits of commerce and solidarity, which have eventually been absorbed and institutionalized by local governments into policies and politics of participation [7].

Therefore, the Mediterranean basin has historically proven a fertile ground for participatory urban governance. Cooperation, however, has shown some limitations in methods and scope. While methodological limitations are beyond the aim of this

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paper, the latter is particularly relevant today: participatory practices have mostly focused on matters of societal concern, engaging citizens in the co-production of services, in the co-design of urban spaces and in culture-led acts of urban regeneration.

The manifold environmental crises which Mediterranean cities are now facing, including heatwaves and the rising cost of energy services [8], are still tackled institutionally and with regulatory tools only, with very few initiatives being activated with the involvement of citizens. This, despite the inherently social nature of energy needs [9] and the emphasis that the European Commission is placing on citizens' engagement as a crucial factor to foster an effective green transition – as envisioned by programs such as the New European Green Deal strategic plan [10] and the New European Bauhaus initiative [11]. The decades-long participatory experience of local administrations and of citizens in Mediterranean Europe has provided effective pathways to collaboration in tackling urban issues. The paper deals with methodologies and lessons learned from Italian experiences carried out in the single geographic scenario of Bologna, which can be taken as a relevant example of how knowledge on participatory processes can be capitalized in the green transition of cities, and how this transition can be accelerated through collaborative practices.

2 Paper Structure and Methodology

The paper will examine innovative collaborative and co-design processes with the aim of understanding the replicability, scalability and applicability of this knowledge and the related tools and practices to address more effective green transition actions in contemporary cities. The metropolitan city of Bologna is a reference for several reasons: it's positioning in the Mediterranean area has turned it into a strategic crossroad and an ideal testing ground for strategies addressing cross-cutting issues at the Mediterranean and European levels; its long and established tradition of grassroots activism and collaboration [12], which provides abundant data about participatory processes and multi-stakeholder governance; its active commitment in fostering and implementing policies aimed at sustaining both Green and Digital transition. Such effort led to the recent nomination of the municipality among the 100 European cities adhering to the EU-funded mission "100 climate neutral cities by 2030 by and for the citizens" [13]. Each selected city will have to develop and implement a "Climate City Contract" that will constitute a co-created political commitment to the EU Commission, to national and regional authorities, and especially to their citizens. Thus, communities' involvement is among the main evaluation criteria of the candidates, crucial for the success of the mission by virtue of citizens' role as key political actors, users, producers, consumers or owners of buildings and transport means.

Aware of the strict relation between the environmental transition process and participation of citizens, and thanks to its longstanding experience in both realms, Bologna is working towards citizens' broad involvement in the care and regeneration of urban public spaces, aiming at combined improvements in terms of quality of life and spaces, accessibility and climate resilience [14].

The three case studies, described in the next paragraph, were selected to cover a broad typology of initiatives and to investigate the methods and tools that were used: a major focus is dedicated to consolidated application realms for participatory practices, such as culture, the commons, regeneration, adaptive reuse of spaces, urban governance. In so doing, specific attention will be devoted to the experience gained within the authors' direct research activities, which have been including applications and experimentations in the built environment that imply inclusive planning and design practices implemented in the city of Bologna. Cases are illustrated with the aim of recognizing, analyzing and comparing recurrent and transversal aspects – highlighting the participatory approach, field of application, actors/stakeholders involved, objectives, results obtained, and strategies related to the collaborative processes adopted, which could be replicated in the Mediterranean context, contributing to a just ecological transition.

3 Insights from Three Collaborative Experiences in Bologna

3.1 The H2020 Rock Project: Shaping Urban Futures Through Collaborative Heritage Transmission

The experience of the H2020 ROCK – Regeneration and Optimization of Cultural Heritage in Creative and Knowledge Cities (GA730280) project, in which the Bologna Municipality was the coordinator and one of the demonstrators, has been useful to test the model of 'Collaborative City' [15] thanks to the involvement of a dense network of stakeholders and local actors, supported by enabling technologies and open data. The added value of such initiatives is that they exemplify how citizen engagement in urban regeneration and environmental sustainability issues are intertwined, as are the social or behavioral dimensions and the physical one, concerning the built environment.

In the frame of the ROCK project and in collaboration with the city agency "Foundation for Urban Innovation" (FIU), the Department of Architecture of the University of Bologna and the Municipality carried out some experimentations distributed in city-central underused or neglected public spaces, triggering regeneration processes that featured social inclusion, accessibility and sustainability, with a substantial focus on environmental solutions and greening actions for the mitigation of Urban Heat Islands (UHI).

Co-design, self-construction and co-management were at the basis of the methodology: most of the transformations were temporary pilot experimentations, not only co-designed but also co-constructed by citizens and university students. The technological constructive systems were low-cost and did not require specific skills, in order to be applied by non-professionals. Such experiences demonstrate the possibility to influence long-term urban dynamics, attempting to slow down the threat of climate and global changes with small local and easily implemented efforts, and to re-activate communities as well as places.

3.1.1 "The Five Squares" Re-Use and Greening Co-Design Project

The ROCK project developed a coordinated synergic set of pilot actions in the historic Bologna University area, to test a sustainable urban regeneration approach pivoted on local Cultural Heritage (CH) and based on co-creation/participatory processes, enabling technologies/tools and greening solutions.

Piazza di Porta Ravegnana, Piazza Rossini, the terrace of Opera House in Piazza Verdi, Piazza Scaravilli and Piazza Puntoni, were involved in "The Five Squares" workshop developed within the programming of the "Bologna Design Week" and "Researchers' Night" in September 2019. The workshop followed the preparatory phases previously set up by the ROCK project, such as the U-lab participatory laboratory, based on the Living lab methodology [16], and the applicative premises, such as the temporary installation "Malerbe" (Piazza Scaravilli, 2017–2019). Malerbe experimented with the effects of the combination between physical transformations and innovative uses of public spaces, making CH more accessible and testing greening solutions [17] (Fig. 1a). The "Five Squares" co-design workshop was followed by two temporary but impactful implementation actions: "Green Please! The meadow you don't expect", a first redefinition of the Piazza Rossini square, and the "U-Garden", providing a new set-up of the Opera House terrace (Fig. 1b). The first one, in particular, connects the experimentation of greening

(a) (b)

Fig. 1 The ROCK project temporary experimentations: "Malerbe" in Piazza Scaravilli during the self-construction workshop on July 2017 (**a**) and "U-Garden" on the terrace of the Municipal Theatre of Bologna, during the opening event, July 2019 (**b**) (Credits: ROCK Project).

Fig. 2 The "Green Please 2.0" installation in Piazza Rossini was completed in June 2020. (Credits: ROCK Project)

solutions, local communities' engagement practices and monitoring tools to evaluate the project impacts [18].

The interest raised by the "Green Please" temporary installation, which substituted a parking area with a vegetable meadow, led to a successive phase of transition, "Green Please 2.0! The green you don't expect", that will finally accompany the square to the permanent transformation into a pedestrian and regenerated space, under the pressure of citizens that embraced the new setup of the square. This the second temporary transition project (realized by FIU, with the scientific collaboration of the Department of Architecture – University of Bologna and BAG Studio) represents a further development of the previous one, embedding more in-depth educational, social and awareness purposes on ecological issues, environmental and common CH care (Fig. 2). Another relevant aspect of the ROCK pilot actions is that the physical transformations and the citizens'/stakeholders' involvement were supported by the use of enabling technologies that allowed to monitor the environmental – and indirectly social – impacts of the envisaged and implemented transformations. Environmental microclimatic simulations were performed using the software ENVI-met [19] to analyse different greening solutions and to evaluate the optimal configuration both in terms of mitigation of the UHI phenomenon and in terms of outdoor comfort conditions improvement. Moreover, monitoring visitors' presence was allowed using crowd analysis sensors to evaluate space usability, before and after the interventions.

3.2 *The* Atelier *of 'Urban Innovation Lab', Bologna: A Community Space to Co-design the Future of Urban Transformations*

"Urban Innovation Lab – Bologna another way" [20] represents a further display of useful tools and strategies in collaborative processes fostering awareness, knowledge sharing and community involvement on topics of common interest for the contemporary cities. The Lab – inaugurated in December 2021 and developed within the "Quadrilatero della Cultura" (Cultural District) programme [21] – is a permanent, multimedia and interactive installation presenting an original storytelling of the metropolitan city of Bologna and its changes over time. The freely accessible spaces are distributed in different halls between the Palazzo Comunale (City Hall) and the Salaborsa library, connected and fully integrated with the surrounding open public spaces located in the heart of the historic center. The design, curatorship and prototyping are the result of a collaborative process coordinated by FIU and carried out by a multi-disciplinary research team involving different Departments of the University of Bologna, the Municipality, several cultural institutions, and professionals.

Contents and data, equipment and technologies, traditional and innovative visual storytelling strategies characterize in a specific and integrated way the five environments, which articulate the Lab. The *Gallery*, the entry threshold to the visit route, is a dynamic and interactive narration of the city from the 1900s to date, tracing the changes and combining historical images and maps with current ones; the *Boulevard* offers an immersive experience in the contemporary city of flows, connections and infrastructure; the *House* hosts data and information on places, topics and visions of the city (e.g., the city in motion, the city of greenery, the city in transformation, etc.), displaying the contents on a large maquette supported by AR; the *Studio* is a data-room for thematic in-depth study and data visualization on the city, based on diagrams and maps from the Bologna Urban Atlas; and, finally, the *Atelier* is as a workshop area where to imagine and contribute to the future transformations of the city.

The Lab is not simply an exhibition space but stands as an interactive experience directly involving the wide target of visitors and users that daily cross the area – including professionals, researchers, university students, citizens, schools, tourists, and so forth – in data collection and content co-production.

To that end, the *Atelier* is the environment that presents the most marked vocation as operative platform for community engagement, reflecting the horizontal and collaborative approach of the Urban Innovation Lab.

The *Atelier,* inspired by places of experimentation such as the craftsman's workshop or the designer's office, is a laboratory area for research and discussion with a specific focus on transformation processes involving urban public spaces. The same concept guided the two main elements that define the layout of the room and support the co-design activities: an instrument wall that collects the contents, and a worktable enabling analog and digital design interactions. With the aim of

Fig. 3 The *Atelier*, pictures of the environment (**a**) and co-design activities supported by the available equipment, the panel of instruments and the worktable (**b**). (Credits: UNIBO)

addressing all the different components involved in urban transformation processes, and strengthening the engagement of a wide range of potential stakeholders, the *Atelier* provide several activities – guided tours, talks and workshops – and supporting tools, including an illustrated glossary, a materials database, an atlas of best practices at different geographical scales, a small library, a board for educational activities, a digital archive and touch screens to experiment co-design experiences on some strategic areas of Bologna (Fig. 3).

The *Atelier* periodically addresses different and transversal topics significant in describing domains and challenges of contemporary cities, ranging from creative and cultural collaboration, social inclusion, health and life quality, greenery and sport, sustainable infrastructure, ecological transition, and so forth. The topics are investigated by the users both in free and mediated modes, supported by the knowledge instruments. The open and operative abacus of strategies and solutions, presented in the form of good design practices referring to case studies or experimented through the laboratory activities, covers among others ephemeral and temporary actions able to transform the perception of places and enable a mix of uses; intervention on mobility system introducing new dynamics in the urban context, promoting safer pedestrians and cycle paths; reactivation or recovery of neglected or abandoned small buildings and areas as shared facilities; enhancement of green areas and parks with different vocations and equipment; networking programs as tools to define different spaces as coherent and recognizable systems. What is considered as relevant is not only the physical transformation of places, but all the aspects involved in the project in terms of actors involved, actions, processes, uses, impacts and results.

3.3 The H2020 GRETA Project: Facilitate the Energy Transition Through the Active Participation of Citizens

GRETA – Green Energy Transition Action is an H2020 Research Innovation Action (GA 101022317) started in 2021. It has proven a particularly timely support framework in light of the rising energy cost, the subsequent increase in energy poverty levels and the EU imperative to reduce import dependency through clean, affordable energy. The GRETA project aims at producing comprehensive and actionable insights to support the design of EU policies that more effectively engage citizens in the energy transition. It wants to contribute to the improvement of the understanding of the energy citizenship phenomena, within and beyond energy communities, with the final goal to design and testing mechanisms for behavioral change. These mechanisms, conceived and to be tested within the project, are the Community Transition Pathways (CTPs): routes that support individuals and communities in transitioning between different levels of citizenship engagement and in enhancing positive energy citizenship behaviors (Fig. 4). GRETA is investigating how CTPs can strengthen and regulate the relations among the actors involved in the transition through Energy Citizenship Contracts (ECCs). ECCs are a specialization of the Climate City Contracts envisaged by the "100 climate neutral cities by 2030" mission, to support the multi-level co-creation process of cities' transition.

GRETA is working within six case studies in different European Countries, including in the Mediterranean area (Italy, Spain, Portugal), adopted as pilot experimentation of specific actions, policies and tools which include the adoption of renewable energy resources, use of electric vehicles, monitor their energy consumption, co-planning of mobility programmes, and an empirical citizen consultation on the emergence of energy citizenship. The Italian case study is located in the Pilastro/Roveri district in Bologna, a mixed-use area (industrial and residential) where strategies are being tested for tackling injustice and exclusion. Engagement mechanisms have been established that are expected to elevate the community to a more active engagement level. The on-fields initiatives are designed and managed in synergy

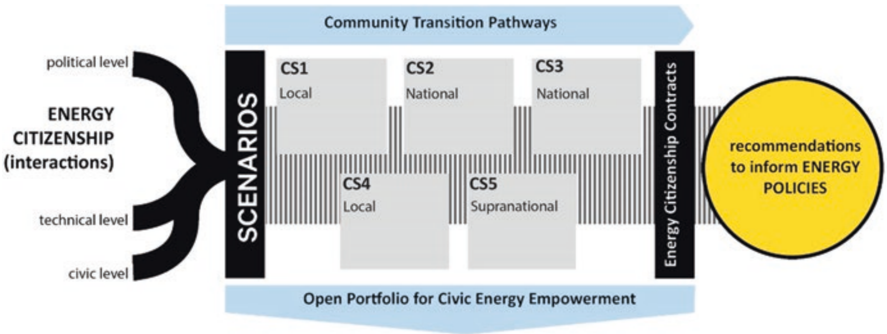

Fig. 4 GRETA Project. Community Transition Pathways (CTPs) towards Energy Citizenship Contracts. (Credits: Infographic by Martina Massari, re-elaborated by the authors)

Fig. 5 'GRETA lab', co-design activities at the Pilastro-Roveri district in Bologna. (Credits: UNIBO)

with the parallel project GECO – Green Energy Community project (EIT Climate KIC TC_2.2.15_190736_P125-1) that is working to create the first energy community of the city [22, 23].

The "GRETA lab" [24] represents the main instrument to approach energy transition issues, founded on the belief that citizens, companies and policymakers should have a key role in carrying out the energy transition. The lab consists of a set of incremental activities organized in different locations. The district, identified by the University of Bologna research team [25], acts as a testing ground for strategies, urban treks, roundtables with local associations and initiatives dedicated to energy saving, environmental justice, as well as the opportunities for the creation of an energy community.

The preliminary outcome of such a shared pathway (developed during a two-day workshop), is the draft of a co-designed Collaborative Energy Citizenship Manifesto, envisioning the necessary steps to pave the way for a just energy transition towards a low-carbon society, acknowledging needs, roles, responsibilities, and shared goals of the community living and working in the area (Fig. 5). The participatory lab highlighted the main barriers to overcome: a cultural change in life habits and behaviors, greater institutional accountability and the creation of alternative governance mechanisms. In addition to this, the open relationship built among the participants during the implementation of the "GRETA lab", has proven the workshop and the other activities to be effective enabling instruments, to bring out the 'energy' and the power of local communities in recognizing, sharing and participating to the common goals subtended to the green energy transition.

4 Conclusions

The EU Green Deal has made it a founding milestone of its strategy "to make sure that no one is left behind" [26]. This means that policies will have to be designed, actions will have to be implemented, and strategies will have to be crafted that allow for a just transition, and for equitable access of all citizens to greener economic, urban and energy systems. A vision that seems to be necessarily embraced in the Mediterranean basin, considering the drastic increase in the cost of energy to be faced in addition to the more consolidated dramatic consequences of climate change (i.e., rising sea levels, heat islands, drought, etc.). A process that has to be driven by a major commitment of institutions and businesses, combined with true citizens' involvement: this is not only a democratic requirement, but a crucial step in eliciting collective awareness and fostering large-scale behavioral changes towards sustainable lifestyles.

The role of citizens in making changes, especially at the urban level, has been incorporated into official politics for a long time now in many European cities, yet the field of energy transition and of the green economy is still lacking participatory tools and approaches that could make this transition more just and inclusive. The present paper has posited itself as a contribution at the crossroad between domains that have an established tradition of collaboration and emerging collaborative experiments in the energy field. Starting from direct research experiences carried out in the city of Bologna, three different projects with a focus on co-design and collaboration have been analysed on the basis of their domain/topic of intervention, the type of action, the involved stakeholders, the participatory approach and their results and outputs (Fig. 6): the aim has been to identify the major cross-cutting features and characteristics of participatory processes to be transferred into the energy domain and in actions oriented at cities' sustainable transition.

The research has illustrated that practices and tools such as co-construction, co-research, living labs, workshops and co-design actions contribute to fostering bottom-up stances, knowledge creation and sharing, and awareness raising (with great potential in terms of behavioral changes). The positive experiences that are here

	The Five squares (ROCK)	The Atelier (Urban Innovation Lab)	GRETA lab (GRETA)
Topic/field of intervention	Public squares, quality of the public built environment, sustainable transformation of the historic city.	Creative and cultural collaboration, social inclusion, greenery and sport, health and life quality, sustainable infrastructure, and ecological transition.	Green energy transition (energy saving, energy justice, energy communities).
Type of action	Temporary greening and reactivation actions.	Laboratory for experimenting and prototyping urban transformations.	On-site participatory process
Involved stakeholders	Citizens, students, researchers, institutions, and third sector (associations, cultural organizations).	City agency (FIU), researchers, professionals, public and cultural Institutions.	Residents, students, researchers, energy companies
Participatory approach	Co-construction, co-design.	Space used for laboratory and collaborative activities.	Participatory labs
Results / outputs	The squares became pedestrian, and temporary actions inspired middle-term and long-term urban solutions.	Hub of knowledge sharing and co-creation	Co-design of Energy Transition Pathways, Collaborative Energy Citizenship Manifesto

Fig. 6 The table summarizes the three processes' main features. (Credits: elaboration by the authors)

recorded advocate for the scalability of these tools into other emerging domains (as has been the case especially with project GRETA and GRETA lab).

In light of the intense stress put at the Institutional level on citizen agency in sustainable urban transformations, an accelerated incorporation of these approaches and methodologies is necessary in order to tackle major urban issues such as energy justice, which cannot now be disentangled from the social issues that trigger it. Such a domain could greatly benefit from collaborative and multi-scalar environments of action and deliberation such as the ones described above and can lead to reaching EU objectives on both social and environmental justice, as well as triggering a cultural change.

Acknowledgments The ROCK and GRETA projects were funded by the European Union within the H2020 Framework Programme [ROCK G.A. No.730280, GRETA G.A. No. 101022317]. The research in support of the Atelier of Urban Innovation Lab has been developed in agreement with the Municipality of Bologna, 'Digital Agenda and Information Technologies' Sector within the 'Open Laboratory' project in Bologna, funded by Regional Operational Program ERDF European Regional Development Fund 2014-2020 Emilia Romagna, Axis 6 "Attractive and participated cities" Action 2.3.1.

References

1. Sennett, R. (2018). *Building and dwelling: Ethics for the city*. Farrar, Straus & Giroux.
2. Moravcsik, A. (2000). The origins of human rights regimes: Democratic delegation in postwar Europe. *International Organization, 54*(2), 217–252.
3. Bernhagen, P., & Marsh, M. (2007). Voting and protesting: Explaining citizen participation in old and new European democracies. *Democratisation, 14*(1), 44–72.
4. Gal, J. (2010). Is there an extended family of Mediterranean welfare states? *Journal of European Social Policy, 20*(4), 283–300.
5. Gürbüz, S., Costigan, R., & Teke, K. (2021). Does being positive work in a Mediterranean collectivist culture? Relationship of core self-evaluations to job satisfaction, life satisfaction, and commitment. *Current Psychology, 40*(1), 226–241.
6. Carlucci, M., Grigoriadis, E., Rontos, K., & Salvati, L. (2017). Revisiting a hegemonic concept: Long-term 'Mediterranean urbanization' in between city re-polarization and metropolitan decline. *Applied Spatial Analysis and Policy, 10*(3), 347–362. (p. 349).
7. Bianchi, I. (2018). The post-political meaning of the concept of commons: The regulation of the urban commons in Bologna. *Space and Polity, 22*(3), 287–306.
8. Keppas, S. C., Papadogiannaki, S., Parliari, D., Kontos, S., Poupkou, A., Tzoumaka, P., Kelessis, A., Zanis, P., Casasanta, G., & de'Donato, F., Argentini, S. and Melas D. (2021). Future climate change impact on urban heat Island in two mediterranean cities based on high-resolution regional climate simulations. *Atmosphere, 12*(7), 884.
9. Lennon, B., Dunphy, N., Gaffney, C., Revez, A., Mullally, G., & O'Connor, P. (2020). Citizen or consumer? Reconsidering energy citizenship. *Journal of Environmental Policy & Planning, 22*(2), 184–197.
10. *A European Green Deal, Striving to be the first climate-neutral continent*. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en. Accessed on: 12 July 2022.
11. New European Bauhaus. https://europa.eu/new-european-bauhaus/index_en. Accessed on: 12 July 2022.

12. Allegrini, G., & Paltrinieri, R. (2018). Partecipazione e collaborazione negli interventi di comunità: l'esperienza dei laboratori di quartiere del Comune di Bologna. *Sociologia Urbana, 111*, 29–44.
13. European Commission. (2020). *100 climate-neutral cities by 2030 – by and for the citizens. Report of the mission board for climate-neutral and smart cities*. Online. https://op.europa.eu/en/publication-detail/-/publication/bc7e46c2-fed6-11ea-b44f-01aa75ed71a1/language-en/format-PDF/source-160480388. Accessed on: 12 July 2022.
14. Orioli, V., & Fini, G. (2020). Bologna città resiliente: esperienze in corso, Working papers. *Rivista online di Urban@it*, Vol. 2/2020. Online. https://www.urbanit.it/wp-content/uploads/2020/10/BP_Orioli_Fini.pdf. Accessed on: 12 July 2022.
15. Municipality of Bologna, Collaborare è Bologna. http://www.comune.bologna.it/collaborare-bologna/. Accessed on: 12 July 2022.
16. Leminen, S., Rajahonka, M., & Westerlund, M. (2017). Towards third-generation living lab networks in cities. *Technology Innovation Management Review, 7*(11), 21–35.
17. Boeri, A., Longo, D., Orlandi, S., Roversi, R., & Turci, G. (2022). Temporary Transformations to access and experience sustainable city public spaces. *Sustainable city 2020, WIT Transaction on Ecology and the Environment, 249*, 43–55.
18. Boeri, A., Longo, D., Orlandi, S., Roversi, R., & Turci, G. (2021). Community engagement and greening strategies as enabling practices for inclusive and resilient cities. *International Journal of Environmental Impacts, 5*(1), 1–14.
19. ENVI-met software. https://www.envi-met.com/. Accessed on: 12 July 2022.
20. Fondazione per l'Innovazione Urbana. *Urban Innovation Lab*. https://www.fondazioneinnovazioneurbana.it/en/innovazione-urbana-lab-en. Accessed on: 12 July 2022.
21. Emilia Romagna Region. (2020). *Laboratorio aperto di Bologna, Verso il Quadrilatero della cultura di Bologna. Lo spazio culturale e collaborativo più grande d'Europa*, Online. https://www.laboratoriaperti.it/bologna. Accessed on: 12 July 2022.
22. Boulanger, S. O. M., Massari, M., Longo, D., Turillazzi, B., & Nucci, C. A. (2021). Designing collaborative energy communities: A European overview. *Energies, 2021*(14), 8226.
23. GECO Project Website. https://www.gecocommunity.it/. Accessed on 13 July 2022.
24. GRETA Project, News, Case Studies, Italy. *Energy talks: How to bring citizens, businesses and policymakers together*. Online, https://projectgreta.eu/energy-talks-how-to-bring-citizens-businesses-and-policymakers-together/. Accessed on: 12 July 2022.
25. GRETA Project, Case studies, Italy. *Renewable energy district*. Online, https://projectgreta.eu/case-study/renewable-energy-district/. Accessed on: 12 July 2022.
26. European Commission. (2019). *Press remarks by President von der Leyen on the occasion of the adoption of the European Green Deal Communication*. Online, https://ec.europa.eu/commission/presscorner/detail/en/speech_19_6749. Accessed on: 12 July 2022.

Influence of Optical Characteristics of Façades on Pedestrian Thermal Comfort Within the Streets of Manhattan

Benoit Beckers, Jairo Acuña Paz y Miño, and Inès de Bort

1 Introduction

According to New York's standard meteorological year, the 2nd of July is a beautiful and warm day in Manhattan. At noon, a wanderer stops on Park Avenue, right in front of the Lever House, the first glass tower, which is celebrating its 70th birthday this year. The sun is reflecting on several of the high glass facades that surround him. The heat he feels is unbearable. He wonders if it would not be better for him if these façades were painted white. At least half of the sun's rays would be reflected upwards. Perhaps if the towers were dark, like the very first skyscrapers in the city, with their brick façades pierced by small windows. In this case, however, the walls would absorb more radiation, which would be re-emitted in infrared, and it is not sure that the radiation balance would be better for the people passing by. The wanderer returns to the same place on a cold winter day, January 2nd. Even at noon, the sun, too low, does not appear to him either in the sky or on the façades, which reflect only the blue sky. It is as if this icy sky was multiplied and, while shivering, he asks himself the same question as last summer: what would be the best material to cover the façades of Manhattan, if it was to improve the thermal comfort of the poor pedestrians? We propose here a first quantification of these radiative exchanges, carried out on the DART software [6], and summarized in Fig. 7. In order to interpret these results, it is necessary to be able to visualize from where all the radiative contributions that reach the considered pedestrian come from, and therefore to project on the plane the complete sphere surrounding the point of interest [2]. The best

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available projection is the Mollweide one. We begin by recalling and demonstrating its formula so that the interested reader can use it in turn in his own applications.

2 The Mollweide Projection

The Mollweide projection is a pseudo-cylindrical equal area map projection that displays the earth's surface as an ellipse with axes in a two-to-one ratio. In this projection, the images of the parallels are straight lines.

2.1 *Equivalence Between the Area of the Sphere and Its Projection*

The area of a sphere of radius r is equal to 4 π r 2. The area of an ellipse with half-axes a and b is equal to π a b. If the major axis is twice as large as the minor axis: $a = 2b$, it is equal to 2 π b^2 By choosing $b = \sqrt{2}$, the area of the ellipse is equal to 4π. It is therefore equal to the area of a sphere of unit radius.

2.2 *Area of a Spherical Cap*

For a sphere of radius r, the area Aca of the spherical cap bounded by the parallel of latitude α is [3]:

2 2 (1 sin)

$$A_{\text{rac}} = 2\pi\left(1-\sin\right)r^2 \tag{1}$$

2.3 *Area of the Two Subdomains of a Disk Cut by a Line*

In a disk of radius b (Fig. 1), the area A_{sect} of a sector of aperture 2β is to the area π b^2 of the disk as the aperture angle of sector 2β is to 2π:

$$A_{\text{sect}} / \pi b^2 = 2\beta / 2\pi \tag{2}$$

The area of the sector of aperture 2β is therefore equal to β b^2. The area of the triangle formed by the two radii of the sector and the line of intersection is equal to $b^2\sin\beta\cos\beta$. The area of the zone between the chord and the arc of the circle held by that chord is equal to $(\beta - \sin\beta\cos\beta)\, b^2$. With radius $b = \sqrt{2}$, the result is $2\beta - \sin 2\beta$.

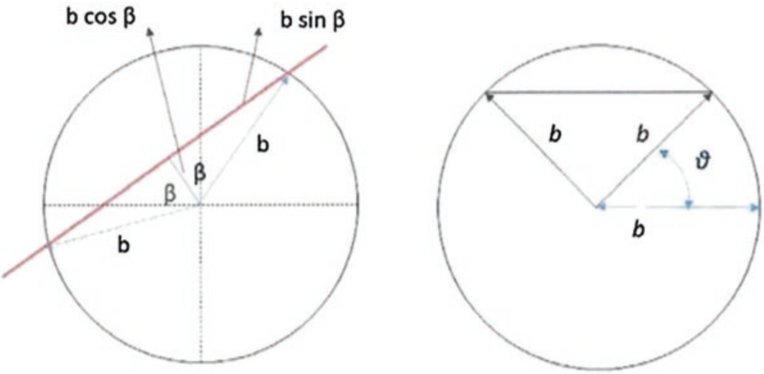

Fig. 1 Areas of the two subdomains of the disk cut by a line

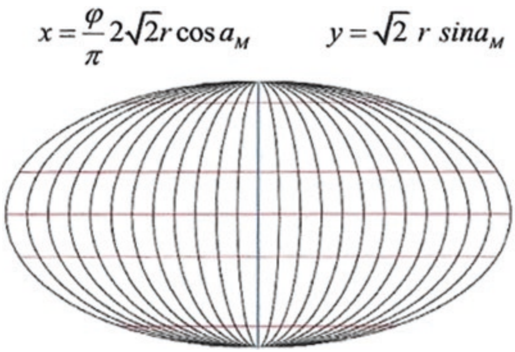

Fig. 2 Earth globe with reference parallels and hourly meridians

By rotating the figure on the left to make the secant horizontal and replacing the angle β with its complement: $\theta = \pi/2 - \beta$, the area A_{cc} of the zone between the chord and the arc of the circle held by that chord is written:

$$A_{cc} = \pi - 2\theta - \sin 2\theta \tag{3}$$

To switch to the Mollweide representation (Fig.2), we multiply by two the x-coordinates and thus the area of the zone between the cord and the ellipse. We can then write the equality between this area and that of the spherical cap:

$$2\pi - 4\theta - 2\sin 2\theta = 2\pi - 2\pi \sin a \tag{4}$$

Simplifying:

$$2\theta + \sin 2\theta = \pi \sin a \tag{5}$$

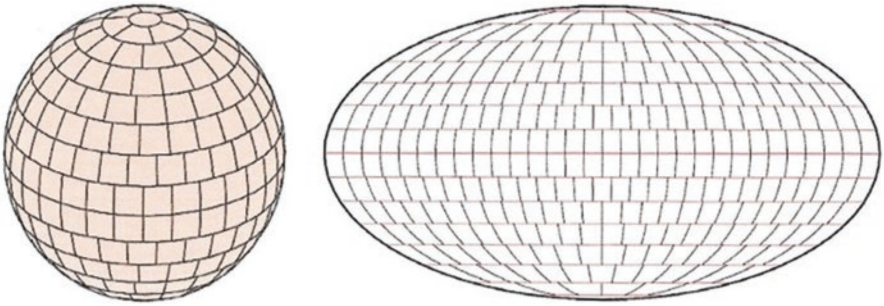

Fig. 3 Sphere composed of elements of the same area

2.4 Image of a Point of the Sphere in the Mollweide Projection

The first step is to calculate the angle θ by solving the nonlinear equation (5), using, for example, the Newton-Raphson method. If we call this solution a_M, the coordinates of the image of the point on the sphere are (Fig. 3):

$$x = \frac{\varphi}{\pi} 2\sqrt{2} r \cos a_M \quad y = \sqrt{2} r \sin a_M \tag{6}$$

2.5 Mesh of a Sphere Made of Elements of the Same Area

3 Calculation of Radiative Exchanges

The Mean Radiant Temperature (T_{mrt}) is the most widely used meteorological parameter to characterize the effect of the radiant environment on thermal comfort [5]. Here, the T_{mrt} is simulated in a complex urban scene using the DART (Discrete Anisotropic Radiation Transfer) code [6].

3.1 Case Study

We study the effect on a pedestrian's comfort of a radical change in the city's façades, going from black to white, and then from white to specular. The exercise consists of comparing five façades at two times of the day, under either perfectly clear or totally overcast skies, at the beginning of summer and then in winter. The observation point is located at the height of a pedestrian (1.5 m) who walks on Park

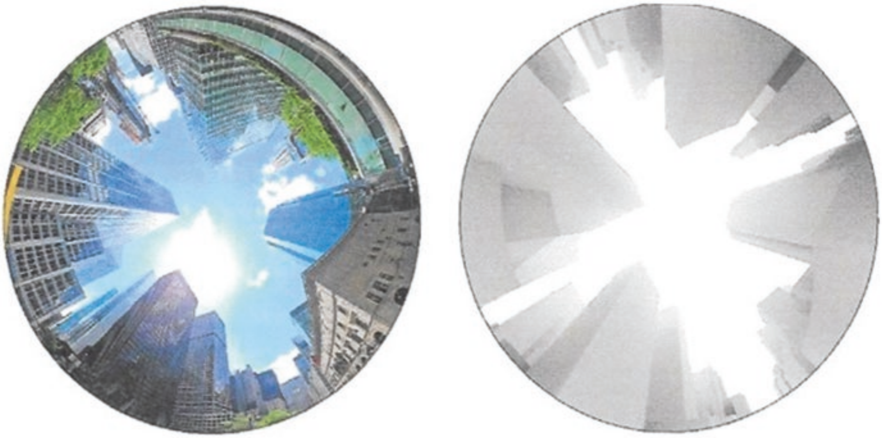

Fig. 4 Photo of Manhattan façades (left); Manhattan model used for the simulation (right)

Fig. 5 3D surface model of Manhattan, with the Lever House building in yellow

Avenue and stops in front of the Lever House (Lat 40.71° Lon −74.00°). Figure 4 shows the upper hemisphere of the scene in a Lambert equivalent projection, on the left in a photographed environment (source: Google Street, June 2019 at 12:00 p.m.) and on the right in the geometric model used here.

The simulation shows two times of the year, July 2 and January 2, at solar noon (12:00 ST). In winter, the sun only reaches a height of 26.41° in the sky, and is not directly visible from the pedestrian's position. In summer, the sun is visible and reaches a height of 72.33°.

The average air temperature in January is −3 °C at night and 4 °C during the day. In July, the air temperature rises to 20 °C at night and 29 °C during the day [9].

The simulation is performed on a model of Manhattan with more than 10^6 faces (Fig. 5) made available to the public by the New York City Hall [7]. A first raytracing is used to determine the sub-area of the ~180,000 faces that participate in

	Simulation				
	I	II	III	IV	V
Reflectance	0%	50%	100%	100%	100%
Specular	0%	0%	0%	50%	100%
Diffuse	100%	100%	100%	50%	0%

Fig. 6 Optical properties of the simulation

radiative exchanges with the observation point. A second raytracing, performed with DART, allows to calculate the shortwave and longwave radiance on this sub-zone.

3.2 Hypothesis

We consider that the city is composed of two materials. The first one represents the ground: it is grey ($\rho = 0.5$, 100% diffuse) for all spectral bands and invariant throughout the simulation. The second represents the buildings: it is variable throughout the simulation, but constant for all spectral bands (Fig. 6).

The radiative transfer of the atmosphere is simulated by atmospheric backscatter. The atmosphere is accurately characterized by gas models and aerosol coefficients. For this exercise, the DART database was used in conjunction with the MODTRAN atmospheric model [4]. An overcast sky is considered to have a visibility of 5 km, while a clear sky has a visibility of 76 km.

4 Results

The mean radiant temperature varies with the city's surface (Fig. 7). In the dark city, the only reflections occur on the diffuse surface of the street. As the reflectance of the surfaces increases, the shortwave contribution becomes more important. At night, a high reflectance means a higher radiative exchange with the sky, which, when clear, is very cold. An overcast sky fosters a T_{mrt} close to the air temperature.

The first curve is the least intuitive, it corresponds to a sunny summer day at noon. Predictably, the mean radiant temperature increases at first, as the city gets brighter. In the second part of the graph, the surfaces remain perfectly reflective, but in a progressively more specular manner. The temperature decreases to a minimum, which corresponds to the semi-specular situation (50% diffuse, 50% specular), and then starts to increase again when the specular behavior takes over. An equivalent Lambert projection, centered on the zenith, allows us to observe the distribution of energy on the building façades (Fig. 8). A white and diffuse city increases the T_{mrt}

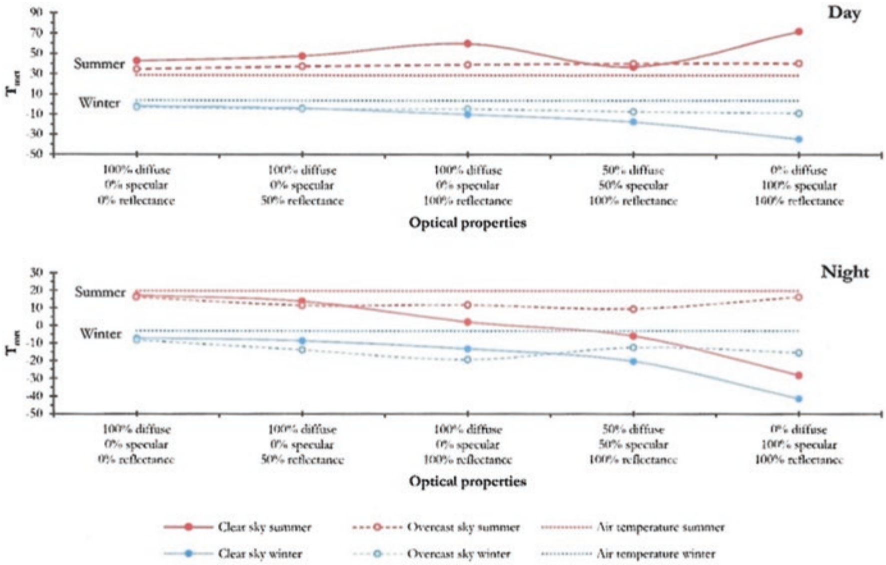

Fig. 7 Mean radiant temperature as a function of the optical properties of the façades: during the day (top) and during the night (bottom)

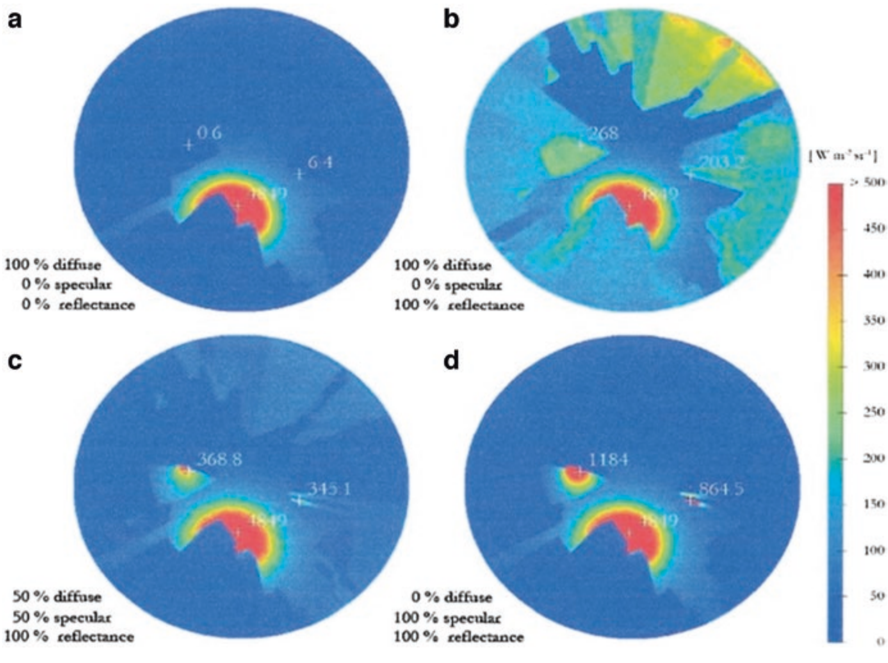

Fig. 8 Shortwave radiance of the scene in Lambert equivalent projections for a summer day under a clear sky in a: (**a**) black city; (**b**) white city; (**c**) semi-specular city; (**d**) specular city

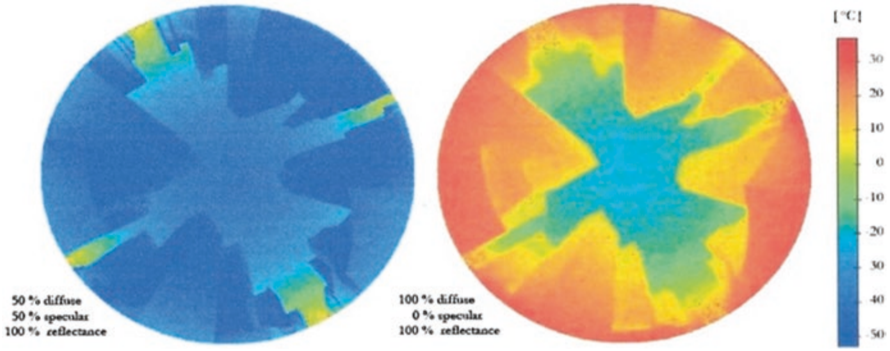

Fig. 9 Apparent temperature for a summer day under a clear sky in a semi-specular (left) and white (right) city

due to multiple reflections. On the other hand, a perfectly specular city allows the sun to be reflected several times, while the scattering of solar radiation is practically non-existent. In a specular city, the concentration of several reflections of the sun on a point can lead to a much higher T_{mrt}. However, in a city with semi-specular surfaces, the partial scattering of radiation has the effect of reducing the multiple reflections and blurring the reflection of the sun. The semi-specular city appears quite dark, and the reflection of the sun is not very intense.

The apparent surface temperature is strongly influenced by the sky reflection (Fig. 9) [1]. In the semi-specular city (left), the low shortwave contributions combined with the very low longwave contributions result in a much lower mean radiant temperature than in the white city (right).

5 Discussion

To study the influence of the scene surfaces on the observation point, it is necessary to know the solid angle they represent on the sphere, so an equivalent projection capable of representing it entirely must be used. The Mollweide projection allows the complete sphere to be mapped on the plane in an ellipse with a 2:1 ratio between axes and small distortion everywhere [8]. The 4π method is thus a convenient tool for visual analysis of the urban radiative environment [2] and the only way to provide such detailed information about the city's radiative landscape. Its value lies in the relationship between the solid angles and the radiometric information of the scene.

Figure 10 shows, on a Mollweide projection, the distribution of solar energy visible on Park Avenue in front of the Lever House. The south is in the center of the image. The sky is clear and the sun has not yet reached its highest position in the sky. Given the diversity of urban scenes, a representation that can synthesize large amounts of information is useful. This image highlights the material and geometric

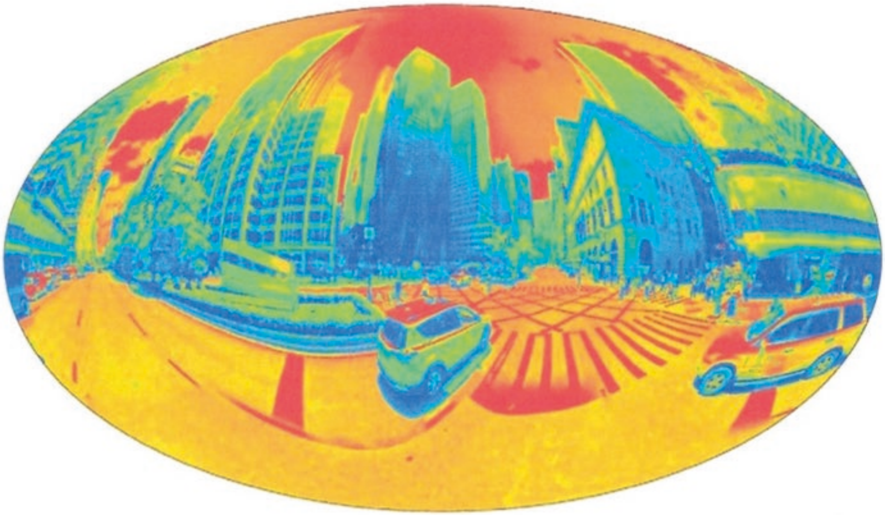

Fig. 10 Projection of Mollweide in front of the Lever House

complexity of Manhattan. In particular, since the observation point is located at human height, the ground occupies almost half of the image. Among the façades, the glass surfaces dominate. They present a very strong contrast of illumination: large sections of dark glass suddenly let the very bright spots of the sun's multiple reflections shine through.

6 Conclusion

The relationship between the Mollweide projection and the solid angle facilitates the understanding of radiative exchange in an urban scene. Although the study is here focused on the façades, it is clear that the ground represents an important solid angle and would be worth studying.

Among the results (Fig. 7), some are unintuitive. In a configuration such as Manhattan, leaving specular surfaces, or painting the entire city white are extreme solutions that are far from optimal for outdoor thermal comfort. In all situations, the opaque, dark, diffuse colors of early industrial cities help maintain a more pleasant T_{mrt}. If a compromise is needed, then the semi-specular city seems to offer the best solution.

This study focused exclusively on radiation. Convective flows are not treated, and conductive flows are very simplified. However, it appears that much more complete studies are now within our reach, and such work is sufficiently justified by the first results presented here.

References

1. Acuña Paz y Miño, J., Duport, N., & Beckers, B. (2021). Pixel-by-pixel rectification of urban perspective thermography. *Remote Sensing of Environment, 266*, 112689.
2. Acuña Paz y Miño, J., Lawrence, C., & Beckers, B. (2020). Visual metering of the urban radiative environment through 4π imagery. *Infrared Physics & Technology, 110*, 103463.
3. Beckers, B., & Beckers, P. (2014, July). *Reconciliation of geometry and perception in radiation physics*. John Wiley and Sons, Inc., 192 pages.
4. Berk, A., Bernstein, L. S., & Robertson, D. C. (1987). *MODTRAN: A moderate resolution model for LOWTRAN*. Spectral Sciences Inc.
5. Fanger, P. O. (1972). *Thermal comfort, analysis and application in environmental engineering*. McGraw-Hill.
6. Gastellu-Etchegorry, J. P., Martin, E., & Gascon, F. (2004). DART: A 3D model for simulating satellite images and studying surface radiation budget. *International Journal of Remote Sensing, 25*(1), 73–96.
7. New York City Planning. https://www1.nyc.gov/site/planning/data-maps/open-data/dwn-nyc-3dmodel-download.page. Last accessed 05 May 2022.
8. Snyder, J. (1987). *Map projection – A working manual*, U.S. Geological Survey Professional Paper 1395, Washington.
9. Typical Meteorological Year of New York. https://energyplus.net/weatherlocation/north_and_central_america_wmo_region_4/USA/NY/USA_NY_New.York.CityCentral.Park.94728_TMY. Last accessed 05 May 2022.

Sustainable Real Estate Development: How to Measure the Level of Introduced Sustainability?

Alice Paola Pomè, Andrea Ciaramella, and Leopoldo Sdino

1 Introduction

The growing interest in sustainable development has resulted in a parallel growth in sustainable measurements. Sustainability indices and ratings are used to measure the sustainability performance of countries (such as EIRIS), companies (such as GRESB) or products and activities (such as LEED in the construction sector) [1]. The concept of sustainable development is traced back to the report "Our Common Future" [2], which first defined the concept and the mission. The United Nations have improved the first declaration of sustainable development through several acts and have reached a specific document in 2015, namely "Transforming our World: The 2030 Agenda for Sustainable Development" [3]. The Agenda 2030 is a framework of 17 goals that have the general objective to guide nations through more sustainable economic growth [3]. The goals, called Sustainable Development Goals (SDGs), are specified through 169 targets, that refer to the 5 P's of sustainability: people, planet, prosperity, peace, and partnership. SDGs have become referring points not only for governments, which have a general perspective of sustainable issues, but also for companies and businesses [4]. Sustainability principles have pushed customers, investors, and business partners to ask companies for higher transparency in showing the environmental, social, and economic effects of their activities [5]. However, the integration of sustainability issues into investment decisions requires data availability, metrics and a well-implemented methodology that allow managers, investors, and customers to monitor impact.

In this context, the real estate sector, part of the Architecture, Built Environment, Construction and Operation (AECO) industry, can play a central role in

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implementing sustainable development. Indeed, the AECO industry is responsible for very high environmental degradation [6]. According to the AECO industry's consumption (about 40% of the total economy's material and energy) and emissions (about 50% of the total economy's greenhouse gas emissions), the introduction of frameworks to reduce the impact has become crucial [7]. The real estate sector generates effects on the society and on the economic market by implementing social infrastructures, generating income, and promoting private investments. Indeed, the real estate is responsible for developing projects for housing, schools, hospitals, and community centers [8]; for involving in the development process several stakeholders, that need metrics to assess the social, environmental, and economic impact of the projects; for generating high levels of employment, as around 110 million workers are working in this sector worldwide [9]; and, for creating from 50% to 70% global wealth in the past 10 years [10]. Moreover, the built environment, developed and managed by real estate, represents the place in which people spent most of their life. The Organization for Economic Cooperation and Development reported that people on average spend more than 90% of their time indoors [11]. These numbers show the importance of developing healthy and safe buildings, well integrated into the environment, and with an optimized economic impact [8]. Therefore, more and more investors in the real estate rely on some indicators that aim to measure the sustainable risks of the investment [12]. Applying sustainability in the real estate means to increase the efficiency and effectiveness of the built environment [13] by making buildings adaptable with the changes of users' needs over time [14]. Buildings have become complex environment that need to manage environmental, social, and governance issues. So, the multiplicity of tools used to certificate the sustainability performance of buildings has become ineffectual to guide investors and managers through more sustainable strategies. The real estate sector has recently brought from the financial sector a new set of factors, namely ESG (Environmental, Social, and Governance), with the purpose to improve the sustainability of real estate investments and operations.

The present research aims to elaborate on the ESG factors and their application in the real estate market. The objective is to implement an ESG framework to evaluate and compare the effects of different investment decisions on real estate operations.

First, after underling the context of sustainable real estate operations, and analysing the state-of-the-art in the application of ESG, the present research concentrates on the definition of the framework. This is made of 52 indicators, divided into nine clusters (Site, Territory, Services, Materials – Technologies, Energy – Emissions, Water, Well-being, Social – Economic, and Governance).

Second, a weights matrix of the indicators is defined. The Analytic Hierarchy Process (AHP) is chosen to implement the weights matrix due to its usability to disentangle complex issues into little steps, and its ability to measure and compare qualitative and quantitative performances.

Finally, the framework is discussed in the conclusion, and some potential improvements are presented.

2 ESG in the Real Estate Industry

The Environmental, Social, and Governance factors (ESGs) reached fast the interest in both the real estate market and the academia. These factors demonstrated the increased investors' concern in the non-financial performance of firms, products, and operations [15]. The United Nations-supported Principles for Responsible Investing (UN-PRI) started promoting the inclusion of ESG in the investment decisions since 2018 [16]. UN-PRI established a standard for evaluating companies of all markets to measure their sustainability performance, divided into three categories, namely Environmental to assess the company's impact on climate change, waste, and pollution; Social to assess the company's impact on working conditions, local communities, and health; and, Governance to assess the company's impact on tax strategy, executive pay, and corruption [16]. UN-PRI evaluate the ESG factors by industry rating agencies and gives different weights to specific indicators according to the industry. As presented by UN-PRI, ESG factors represent a tool for evaluating the long-term impact of investment opportunities [17].

The ESG implementation in the real estate offers a practical and transparent way to connect progress on sustainable initiatives to the estimation of long-term impact. The study conducted by Larsen [17] shows that real estate operators are leveraging their sustainability initiatives to attract more tenants, reduce operating expenses, and improve investment programs. On the other hand, investors are looking not only at financial effects but also at environmental and ethical concerns [18]. Even if a lot of rumours on ESG factors in the real estate market, the effects of more sustainable investments have received little attention. However, those studies that focused on the relationship between profit and sustainable issues (especially, social, and environmental) have shown a positive correlation for this market [19]. This correlation is nowadays trying to be assessed through the ESG factors, which aim to measure the direct and indirect impacts of activities, assets, or companies [20]. ESG refers to the central effects that measure sustainable impact [6]. The capital market, which has the aim to commit to net zero portfolios, is incorporating ESG to make investment decisions [20]. According to Deutsche Bank (2021), 95% of all investments will consider ESG factors by 2035. Real estate represents a key market for the global economy, and the global cost of environmental transition is about € 6.35 trillion per year [21]. Eichholtz et al. [22] documented a link between the real estate market and the energy efficiency of properties. This link suggests a positive correlation between the "greenness" of the portfolio, assessed through green certifications (such as LEED), and the operating performance of the investment [22].

2.1 Regulatory Framework

The European Green Deal aims to make Europe the first climate-neutral continent by 2050 [23]. Throughout the "Action Plan Financing Sustainable Growth" [24], the European Union proposes a 10-point plan with the objective to reorient capital flows towards sustainable investments, integrating sustainability into risk management and promoting transparency and encouraging a long-term vision. To mitigate the environmental issues caused by the AECO operations, the European Union has issued several legislative frameworks, such as the Directive on the energy performance of buildings (2010/31/EU), and the Directive on the construction phase of buildings (2012/27/EU). These directives frameworks issued by the European Union since the beginning of the new millennium had the focus on reducing the energetic expenditures of buildings [25]. Thus, the main requirement of these directives was to ask the Member States to build nearly zero-energy buildings from 2020 onward [26]. In July 2021, European Union enacted a proposed revision of the Energy Efficiency Directive with the objective to reduce the greenhouse gas emissions to at least 55% below 1990 by 2030 (the Climate Target Plan), and to reach the zero-emission building stock by 2050 [27]. Although the work of the European Commission, the European building stock is far from being sustainable [28], as estimations highlight that only 25% of the existing European building stock complies with the current standards [29]. Moreover, the adoption of sustainable policies in building interventions means going further in the energy aspect by including social and economic implications [30]. These directives, firstly implemented in the construction phase for solving environmental issues, were then adopted in the management phase for measuring the sustainable (adding also economic and social issues) impact of real estate investment and operations [31]. In 2014 the European Union issued three different directives for the real estate sector. Directive 2014/23 focused on the award of concessions for works and services, which governs concessions for public works. Directive 2014/24 established new rules on the procedures for procurement by public contracting authorities, relating to public works and design competitions. Finally, directive 2014/25 established the new minimum reporting standards on environmental and social matters, in relation to personal management, respect for human rights and the fight against active and passive corruption.

As reported in the state of the art, the integration of ESG factors into the investment evaluation process means highlighting the risks and the opportunities of parameters not exclusively focused on financial aspects, but also look at environmental, social, and governance ones. Although there is no specific regulatory framework for the integration of ESG factors in the real estate sector, it may be useful to recall the 20-20-20 package, which had set in 2008 to reduce by 20% greenhouse gas emissions, bring energy savings to 20% and increase the consumption of renewable sources by 20% by 2020. After 2008, the European Commission has established the "Green Deal" in 2019 [23], which reports a detailed action plan with the objective of renovating and improving the efficiency of buildings. So, the European Commission is working on five major aspects:

1. The Sustainable Finance Disclosure Regulation (SFDR) establishes rules for classifying and reporting on sustainability and ESG factors in investments. SFDR was developed to improve transparency, with the main goal of preventing greenwashing, as well as to direct capital towards more sustainable investments/products and businesses;

2. Regulation 2020/852/EU (18th June 2020), namely the Taxonomy Regulation which establishes the birth of the first system in the world for the classification of sustainable economic activities, establishing the criteria for determining whether an economic activity can be considered environmentally sustainable. The Taxonomy identifies six environmental and climate objectives to be respected: (1) Mitigation of climate change; (2) Adaptation to climate change; (3) Sustainable use and protection of water and marine resources; (4) transition to the circular economy, also with reference to waste reduction and recycling; (5) Pollution prevention and control; and (6) Protection of biodiversity and ecosystem health.
3. The Delegated Regulations 2020/1816/EU and 2020/1817/EU concerning respectively the "Climate Transition" and "EU Paris-aligned Benchmark", with the aim to reduce the carbon footprint of a standard investment portfolio in the context of the Paris Agreement they aim to select only the elements that contribute to the achievement of the 2 °C target established as the maximum increase in the earth's average temperature.
4. The "Shareholder Rights Directive II" (SRD II) is a directive on shareholders' rights issued to involve shareholders and increase the level of companies' transparency.

At the Italian level, however, it is necessary to consider Legislative Decree 254/2016, which refers to the European Commission Directive 95/2014 and expresses itself on the subject of "communication of non-financial information and information on diversity by certain companies and certain groups of large companies" (Gazzettaufficiale.it 2017). This Decree aims to provide integrated and complementary information with respect to what a company reports in the annual financial statement. Then, in 2017, the Italian parliament issued the Minimum Environmental Criteria (Criteri Ambientali Minimi – CAM) to introduce the minimum requirements to be met for interior furnishings, buildings, and textile products in terms of energy efficiency, acoustic comfort, and sustainability of the materials used. The purpose of the CAMs was to achieve the objectives set out in the action plan for the environmental sustainability of public administration consumption and the promotion of sustainable production and consumption and circular economy models. As regards energy efficiency specifically, the CAMs refer to the indicators defined in the Ministerial Decree of 26 June 2015. While looking at the issue of environmental sustainability of materials and products, these must meet certain criteria relating to the percentage of recycled materials.

2.2 Framework for Assessing Sustainable Development in the Real Estate

The link between the real estate sector and the ESG factors has been pointed out not only by the academia environment but also by the market and the European Commission. This relevance led to the implementation of frameworks that use ESG factors for evaluating the real estate sector. The most used frameworks are compared in Table 1. A substantial difference emerges in the structure and purpose of the single framework. For example, the Agenda 2030 [3] system is a general guideline, focused on achieving an objective without reporting technical references for calculating the impacts; while the SASB system [32] is a technical and implementation guideline, focused on technical references for the calculation.

Table 1 Comparison between the most used frameworks for the sustainability evaluation of the real estate sector – elaboration by the authors

Framework	Description	Sector	Structure	Supporting	ESG focus
Agenda 2030 (SDGs)	Larger framework, consisting of 17 goals (the Sustainable Development Goals – SDGs) and 169 implementation targets. The system, adopted for a wide range of materials and sectors, aims to increase the attention to sustainable development matters	All	Goals & targets	International & national policies	E + S + G
GRI	The Global Reporting Initiative (GRI) is a tool that aims to assess the sustainability impacts of organizations. GRI has defined a series of "reporting standards" (including real estate) that allow organizations to identify and compare their own impacts on ESG	Real Estate	Hierarchical table	Framework for organizations	E + S + G
SASB	The Sustainable Accounting Standards Board (SASB) aims to define a series of standards to guide organizations towards sustainable development. The specific framework for real estate investigates four main issues, namely Energy Management, Water Management, Management of Tenant Sustainability Impact and Climate Change Adaptation	Real Estate	Hierarchical table	Framework for organizations	E
GRESB	GRESB measures the ESG performance of individual real estate assets and portfolios based on self-reported data from companies. GRESB integrates other energy, green or sustainability certification systems into its assessment to improve the transparency of the assessment processes and create a system that allows comparison	Real Estate	Descriptive guide	Framework for organizations	E

(continued)

Table 1 (continued)

Framework	Description	Sector	Structure	Supporting	ESG focus
ICMS	The International Cost Management Standards is an international standard that aims to improve design and construction processes by considering comparable and consistent data at international level that look not only at economic costs but also environmental ones	Real Estate	Hierarchical table	Framework for organizations	E
B Corp	B Corporation is a system that measures the sustainability performance of companies, evaluating the impacts of four categories, namely Community, Environment, Workers, Government and Costumers	All	Survey	Framework for organizations	E + S + G

Generally, all the analyzed frameworks started from the 17 goals of the Agenda 2030 [3], which represents generic guidelines on sustainable development. The most relevant objective for the real estate sector is goal 11 "Sustainable cities and communities", which asks to "create inclusive, safe, resistant and sustainable cities and human settlements". Even if some targets specify the actions to take for implementing goal 11, the Agenda 2020 represents a strategic guideline that must be implemented by specific legislation. Therefore, several national and international bodies start reasoning on more specific frameworks, such as GRI [33], SASB [32], GRESB [34], ICMS [35], and B Corporation [36]. Among these frameworks, the most used in the real estate sector is the Global Real Estate Sustainability Benchmark (GRESB). GRESB is a commercial real estate reporting tool for giving environmental social, and governance data on real estate portfolios [34]. GRESB has be implemented in 2009 by pension managers that noticed the lack of the real estate sector in measuring the ESG impact of real estate portfolios. A review of GRESB shows that even if the framework reports very well where the real estate stands on sustainable development, it fails in showing environmental and social impact [8]. The majority of the ESG factors evaluate the governance impact by concentrating on the organizational level, such as board governance, company policy, and employee satisfaction, while few indicators evaluate the sustainable level of products and services [8]. This analysis demonstrated that the sustainability impact created by the sector should be evaluated at a product level, as real estate is based on physically developing products with which humans interact [8].

2.3 State-of-the-Art Outcomes

What emerges from the state-of-the-art is that the real estate sector needs to understand how each decision in the built environment is impacting environmental, social, and governance issues. This evaluation should measure all real estate investments not only for showing investors the ESG impact but also for suggesting to developers and stakeholders the sustainable directions to perform during the design and construction phases. Therefore, the present research reasons the ESG to implement a new framework for evaluating the sustainability performance of real estate investing developments.

3 Methodology

After the analysis of the state-of-the-art on the application of ESG in real estate, the present research concentrated on the development of a framework for the evaluation of the sustainability performance of real estate investments. The comparison of the previous frameworks has been used to implement the structure of the new ESG framework. Then, the research is developed into two major steps:

1. Implementation of the Matrix of indicators; and
2. Development of the Matrix of weights.

The first step, Implementation, has been developed thanks to the comparison between the previous ESG frameworks. While for the second step, Development, a specific decision-making model has been chosen. For this step, an experimentation test has been conducted throughout 17 expertize in real estate. Finally, the conclusions report some potential strengths of the framework and some future developments that the authors intend to implement.

4 Matrix of Indicators

The analysis of the state-of-the-art and the comparison of previous frameworks has demonstrated the benefit of identifying individual indicators to show the sustainability performance of operations. Therefore, the research has identified an ESG system for the sustainable evaluation of the real estate development process. The system consists of 52 indicators, divided into 9 categories (Fig. 1).

These 9 categories have been identified as the collectors of the most relevant elements for the evaluation of the sustainability performance of real estate development processes. Thus, "Site" and "Territory" identify the lot to which the real estate development process belongs; "Services" shows the interactions that the site has with the neighbourhood and its services; "Materials – Technologies", "Energy and

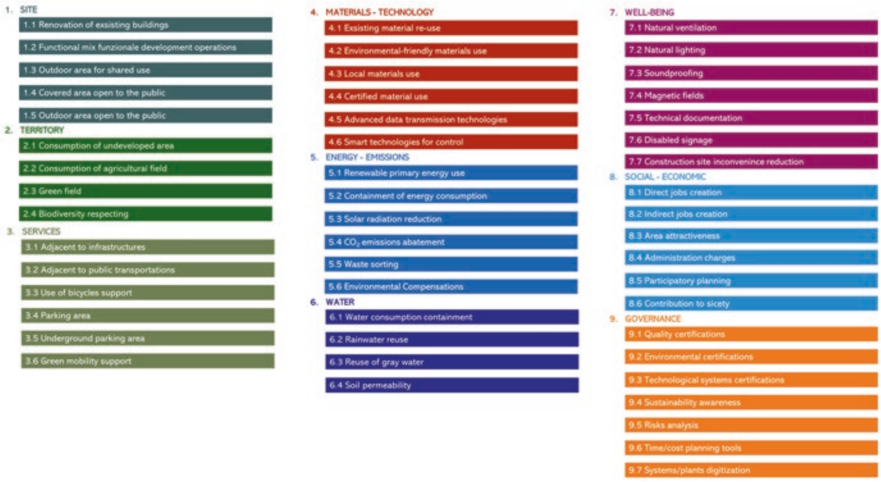

Fig. 1 The 9 categories and the 52 indicators of the Matrix of indicators – elaboration of the authors

Emissions", "Water", and "Well-being" identify the construction characteristics of the building and the effects that design choices have on users' comfort; and, "Social – Economic" and "Governance" show the effects that the real estate investment generates on users and on all society, which also indirectly is impacted by the real estate development. The state-of-the-art has also highlighted the importance of correlating the indicators with the SDGs to specify the actions to be taken for integrating sustainable development into real estate development projects. This correlation allows to identify the long-term impact of the real estate development project on sustainable development. Moreover, to highlight the sustainability performance of the project and the impact of the management and territorial development of the real estate investment, the framework needs to show the ESG intention of each indicator. ESG investment reflects the desire to invest in companies (or, projects) that seek to solve social and environmental problems by practicing solid corporate governance of the real estate development process. Finally, the framework needs to highlight the territorial effects of the real estate development process by defining for each indicator the territorial scale impact. Therefore, as shown in Fig. 2, the Matrix of indicators reports:

- On the columns up the 52 indicators, are divided into the 9 categories;
- On the raws the 17 SDGs: the sustainability performance of the real estate development project; and.
- On the columns down the ESG intention of the real estate investment (E, E-S, E-G, S, S-G, G, or E-S-G) and the generated territorial effects (local, regional, or global).

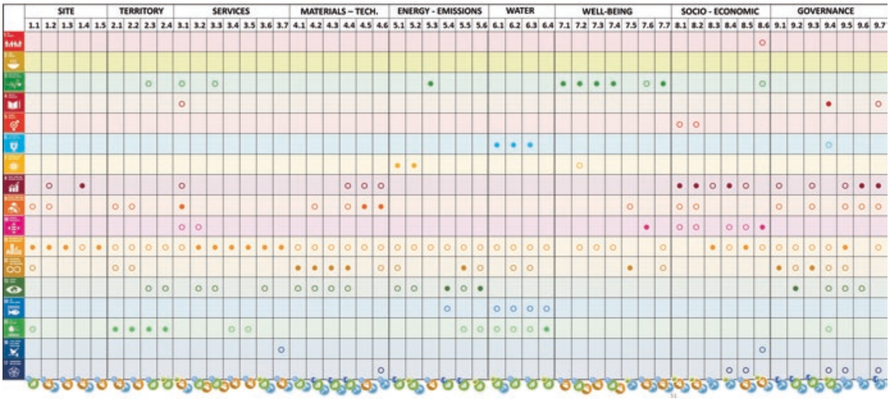

Fig. 2 The Matrix of indicators – elaboration of the authors

5 Matrix of Weights

After the implementation of the structure, the authors have evaluated the indicators by developing a weights matrix. Each real estate project has limited resources, and these must be distributed over a range of parameters in the decision-making and subsequently executive phase. The risk is not correctly considering the cost of the lost opportunity in distributing resources in a non-optimal way or more simply not providing proper attention to an issue that could subsequently prove to be fundamental or critical. The use of a system of weights to be applied to each indicator is necessary to implement the decision-making process by concentrating resources on the most critical issues. The weight system improves awareness of the importance of a particular indicator with respect to the total and the impact it generates at the ESG level.

To identify which indicators, have the greatest impact on the sustainability performance of the real estate investment, the authors used the Analytic Hierarchy Process (AHP). AHP, developed by T.L. Saaty in 1980 [37], is a decision-making tool that uses the principle of hierarchic composition to derive priorities of alternatives with respect to multiple criteria [37]. AHP is one of the most used methodologies to legitimize the decision-making process of multiple criteria which is based on the definition of a hierarchy of importance among the different elements under analysis. The main advantage of the AHP methodology is the flexibility with which it can be adapted to various applications [38]. It has been used in various areas, including planning, best alternatives selection, resource allocation, and process optimization. The AHP methodology is based on the so-called Saaty Scale [37], which provides a score from 1/9 to 9. "1/9" expresses the extreme prevalence in terms of the importance of the element placed on the column compared to the one placed on the line. While "9" indicates the extreme prevalence of the element placed on the row compared to that placed on the column. All the numbers between these two extremes form a scale with an increasingly lower relative prevalence between the two indicators.

In order to define the hierarchy importance of the 52 indicators, the authors have defined a sample of seventeen experts in the real estate field, including academia researchers, facility managers, and professionals. The compilation of the sample is the most critical step of the AHP. Indeed, in the compilation of the evaluation form, the sample may make mistakes in two orders. The first possible mistake is the lack of congruence in the comparison of the indicators, while the second is the lack of congruence in the weight attributed to the indicators. So, for example, let's take a matrix with three indicators (A, B and C). The first possible mistake is to evaluate A > B, B > C, but then C > A. In this case the indicator A must be evaluated as more important than C. The second error, however, is to evaluate A >> B; B >> C, but then A > C. In this, the indicator A, much more important than B, which turns out to be much more important than C, must be evaluated as much more important than C (A >> C). To overcome these errors, the standardization method is applied in the present research, which provides for an imposed consistency index of 10% [37]. This index, if exceeded, forces a revision in the compilation of the evaluation format. Furthermore, to support the respondents in their compilation, the present research has developed an evaluation format that provides for the compilation of only the upper part of the diagonal where "FILL IN" is reported, see Fig. 3. Then, once the upper half of the table has been filled in, the lower one will already be calculated, representing the inverse of the weights assigned in the upper half. An eigenvector is then calculated for each individual indicator, which is divided by the total eigenvector allows to obtain the percentage weight of an indicator with respect to the total.

The sample of seventeen experts filled in the evaluation format individually, after an introduction by the authors that defined each indicator. The obtained results were compared, obtaining a minimum, a maximum, and an average of the weights in percentage (Fig. 4). The average percentage weight represents the weight to be applied to evaluate each indicator defined within the designed framework.

From the average results, category "8. Social-Economic" seems to greater impact (16.90%) on the sustainability performance of real estate investments. Within this category, the most significant indicator is "8.1 Direct jobs" (39.13%), followed by "8.2 Indirect jobs" (27.54%), while the least impacting "8.4 Administration charges "(2.68%). The category "8. Social – Economic "is followed by the category "7.

			2.1 Consumption of undeveloped area	2.2 Consumption of agricultural field	2.3 Green field	2.4 Biodiversity respecting
2. Territory	2.1	Consumption of undeveloped area		TO FILL IN	TO FILL IN	TO FILL IN
	2.2	Consumption of agricultural field	...		TO FILL IN	TO FILL IN
	2.3	Green field	...	...		TO FILL IN
	2.4	Biodiversity respecting	...	...	...	
	4	Weight	...	...	...	...

Fig. 3 Evaluation format for the Matrix of weights – elaboration of the authors

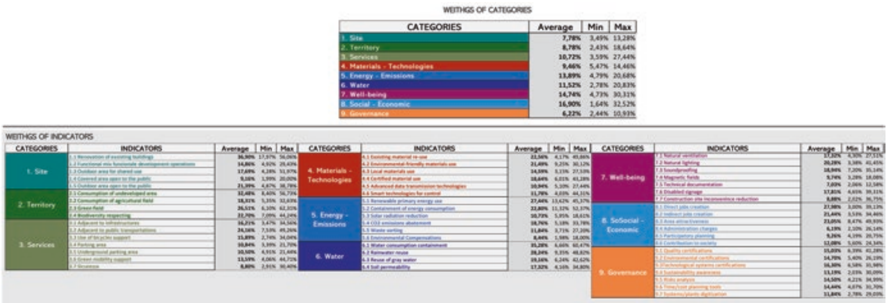

Fig. 4 The Matrix of weights – elaboration of the authors

Well-being"(14.74%), in which the most significant indicator is "7.3 Acoustic insulation"(25.98%), followed by "7.4 Disabled signs" (23.35%). While the category that according to the sample of experts has the least impact on the sustainability performance of real estate investments is "9. Governance" (6.22%), in which the least impacting indicator is "9.7 Digitalization of systems and plants" (2.78%).

6 Conclusion

This research represents a first step into the implementation of the ESG framework for evaluating the impact – and the best options – of a real estate development investment. The experimental step of the present research highlights the importance of including social, economic, and governance indicators in the evaluation of the sustainability performance of real estate development investment. This confirms also what has emerged in the state-of-the-art. Although the relevance of the matter, the research presents some limitations. First, the framework has not been tested on a case study yet. This prevents the authors to test the reliability of the framework. Second, the weights have been evaluated only by a sample of real estate experts. To improve the quality of the "Matrix of weights", future developments of the framework should test the sustainability importance hierarchy of indicators and categories by different categories of samples, such as potential users, and private investors. This step would assess the effectiveness of the ESG framework. However, the research has examined hot topics for real estate and proved that sustainability principles have pushed real estate operators to assess the overall sustainability impact of investments. Therefore, a framework that improves the level of transparency of real estate development projects is relevant to mitigate the overall sustainability impact of the real estate sector. Finally, the present ESG framework represents an improvement of the previous frameworks because it lists together all the indicators that impact the sustainability performance of a real estate development project, and highlights the correlation between indicators, SDGs, ESG intention, and territorial effects.

References

1. Rogmans, T., & Ghunaim, M. (2016). A framework for evaluating sustainability indicators in the real estate industry. *Ecological Indicators, 66*, 603–611.
2. United Nations. (1987). *Report of the World Commission on Environmental and Developmental: Our common future*.
3. Agenda 2030 for Sustainable Development. (2015). https://unric.org/it/agenda-2030/. Accessed June 2022.
4. Sætra, H. S. (2021). A framework for evaluating and disclosing the ESG related impacts of AI with the SDGs. *Sustainability, 13*, 8503.
5. Verbin, I. (2020). *Corporate responsibility in the digital age: A practitioner's roadmap for corporate responsibility in the digital age*. Routledge.
6. Brouen, D., & Marcato, G. (2018). *Sustainable insights in public real estate performance: ESG scores and effects in REIT markets*. https://buildings.lbl.gov/sites/default/files/ESG%20measures%20FinalVersion.pdf. Accessed June 2022.
7. Warren-Myers, G. (2012). The value of sustainability in real estate: A review from a valuation perspective. *Journal of Property Investment & Finance, 20*(2), 115–144.
8. Zaccack, N. (2020). *How real estate developers define and implement their social impact goals through the real estate development process*. Program in Real Estate Development in Conjunction with the Center for real estate. http://34.201.211.163/handle/1721.1/128052. Accessed June 2022.
9. Comaru, F., & Werna, E. (2013). *The health of workers in selected sectors of the urban economy: Challenges and perspectives.* International Labour Office, 2013.
10. Razzaz, O. (2000). *The Land and real estate Assessment (LARA).* The Lincoln Institute of Land Policy and the World Bank Group, 2000, The Land and real estate Assessment (LARA).
11. Environmentally Sustainable Buildings: Challenges and Policies Executive Summary. OECD, Environmentally Sustainable Buildings: Challenges and Policies Executive Summary, http://www.oecd.org/env/consumption-innovation/2715115.pdf. Accessed June 2022.
12. Folqué, M., Escrig-Olmedo, E., & Corzo Santamaria, T. (2021). Sustainable development and financial system: Integrating ESG risks through sustainable investments strategies in climate change context. *Sustainable Development, 29*, 876.
13. Artistizàbal-Monsalve, P., Vàsquez-Hernàndez, A., & Botero, L. F. (2022). Perceptions on the processes of sustainable rating systems and their combined application with Lean construction. *Journal of Building Engineering, 46*, 103627.
14. Beadle, K., Gibb, A., Austin, S., Fuster, A., & Madden, P. (2008). Adaptable futures: Sustainable aspects of adaptable buildings.
15. Ford, J. M., Gehricke, S. A., & Zhang, J. E. (2022). Option traders are concerned about climate risks: ESG ratings an short-term sentiment. *Journal of Behavioral and Experimental Financial, 35*, 100687.
16. UN-PRI Annual Report. (2018). https://www.unpri.org/annual-report-2018. Accessed June 2022.
17. Larsen, T. (2010). Implementing ESG in private real estate portfolios: The case of U.S. and Pan-Europe Core Fund Managers. *Journal of Sustainable Real Estate, 2*(1), 249–267.
18. Gieger, P., Cajias, M., & Fuerst, F. (2016). A class of its own: The role of sustainable real estate in a multi-asset portfolio. *Journal of Sustainable Real Estate, 8*(1), 190–218.
19. Newell, G. (2008). The strategic significance of environmental sustainability by Australian-listed property trusts. *Journal of Property Investment and Finance, 26*(6), 522–540.
20. COP21 - The SustainAbility Institute by ERM. (2021). Connecting ESG, Capital Markets, and CFOs.
21. OCSE. (2021). https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiozMiUpYL5AhXqRPEDHac2A9MQFnoECC8QAQ&url=https%3A%2F%2Fpresidenza.governo.it%2FDAGL%2Fpdf%2FRAPPORTO-OCSE2021.pdf&usg=AOvVaw2XYFDHLC_OBn35yxX9vMLc. Accessed by June 2022.

22. Eichholtz, P. M. A., Kok, N., & Yonder, E. (2012). Portfolio greenness and the financial performance of REITs. *Journal of International Money and Finance, 31*(7), 1911–1929.
23. Green Deal. (2019). https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_it. Accessed June 2022.
24. Action Plan Financing Sustainable Growth. https://www.sustainalytics.com/investor-solutions/esg-research/eu-sustainable-finance-action-plan-solutions?gclid=CjwKCAjw5s6WBhA4EiwACGncZRNE9oPpNigzNc7mC3wHiJOu35Hzjh2ucuTIFj1e1FCnaQJMKzBHIBoCQMoQAvD_BwE#sfdr?utm_term=sustainable%20finance%20disclosure. Accessed June 2022.
25. Geller, H., Harrington, P., Rosenfeld, A. H., Tanishima, S., & Unander, F. (2006). Policies for increasing energy efficiency: thirty years of experience in OECD countries. *Energy Policy, 34*(5), 556–573.
26. E. Parliament. (2012). Council, Directive 2012/27/EU of the European Parliament and of the Council of 25, on energy efficiency, amending Directives 2009/125/E Cand 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance. *Official Journal of European Union, 53*, 1–56.
27. Proposal for a directive of the European Parliament and of the Council on energy efficiency (report). COM/2021/588 final, available https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0558. Accessed June 2022.
28. BPIE. 97% of Buldings in the EU need to be upgraded, Factsheet (2017), available https://www.bpie.eu/publication/97-of-buildings-in-the-eu-need-tobe-upgraded/
29. Verma, S. (2020). *The crest of the Renovation Wave: A toolkit to decarbonise the European building stock, Build*. https://www.buildup.eu/en/news/crest-renovation-wave-toolkit-decarbonise-european-building-stock. Accessed June 2022.
30. Jiménez-Pulido, C., Jiménez-Rivero, A., & García-Navarro, J. (2020). Improved sustainability certification system to respond to building renovation challenges based on a literature re-view. *Journal of Building Engineering, 45*, 103575.
31. Belani, D., Makwana, A. H., Pitroda, J., & Vyas, C. M. (2014). Intelligent building new era of today's world. In *Proceedings of the Trends and Challenges of Civil Engineering in Todays Transforming World*, Surat, India, p. 1–16.
32. SASB. (2022). https://www.sasb.org/standards/download/?lang=en-us/?lang=en-us. Accessed June 2022.
33. Real Estate Sector Disclosure. https://cdn2.hubspot.net/hubfs/2642721/Recursos/Guias%20y%20Estandares/Suplementos%20sectoriales%20G4/GRI-G4-Construction-and-Real-Estate-Sector-Disclosures.pdf. Accessed June 2022.
34. GRESB.com. (2022). https://www.gresb.com/nl-en/. Accessed June 2022.
35. AICE-it.org. (2022). https://www.aice-it.org/it/component/tags/tag/icms. Accessed June 2022.
36. B Corporation. (2022). https://www.bcorporation.net/en-us/movement/about-b-lab. Accessed June 2022.
37. Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation* (ISBN 0-07-054371-2). McGraw-Hill.
38. Saaty, T. L. (2003). Decision-making with the AHP: Why is the principal eigenvector necessary. *European Journal of Operational Research, 145*, 85–91.

Strategies for Frugal Smart Oasis: Figuig as Prospect

Youssef El Ganadi, Sharif Anouar, and Adam Anouar

1 Introduction

The main objective of this research lies in the extension of the smart development model to non-strictly urban contexts such as oasis towns for intelligent and sustainable urban management of their territories. It is necessary to ensure that the smart city is not the prerogative of developed cities. Other contexts such as the oasis of Figuig, characterized by extreme climatic conditions, water scarcity, decaying urban heritage, low financial resources and a lack if not complete absence of technological infrastructure, can benefit from the implementation of the smart city model. Oases can reap enormous benefits in the application of digital technologies to address nowadays challenges such as climate emergencies, the transition towards sustainable communities and the preservation of the heritage amongst many others. It is the adoption of a new intelligent, frugal, and low-cost strategy, capable of adapting to the different specific conditions of an urban context.

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2 Smart Cities

The term smart city represents a new paradigm, a model of intelligent and sustainable urban development that aims to achieve balanced sustainability in the dimensions that make up urban contexts, through the prospective use of digital technologies. Unfortunately, the urban smart model has a rich but multifaceted theoretical framework and lacks a well-defined practical framework. There is no clear definition, strategy or process that can represent a solid practical framework. Despite its popularity, the concept of a smart city doesn't have yet a clearly and universally shared definition [1]. Some authors, talk instead about the credibility of the smart city model, stating that a Smart City, in order to become something concrete, must be able to be analysed with objective evaluation tools that have a scientific basis [2].

A study conducted by researchers from Politecnico di Milano carried out through a bibliometric analysis of about 1067 documents, identified about 18 thematic clusters concerning the scientific field of smart cities. These clusters were selected to identify which were the emerging interpretative models of the smart city. The research identified two dominant interpretive models, the techno-centric model, and the holistic model [3].

On the one hand, the techno-centric model was born in North America under the impetus of one of the leading companies in the ICT sector, IBM. This model assumes that a city, to build its prosperity and achieve a high degree of sustainability, must become intelligent, a goal that can only be achieved through the massive use of ICT technologies, products, and services.

On the other hand, the holistic cluster considers a smart city as a sustainable urban context that cannot ignore its human, social, cultural, and environmental components, and in which the factor related to technological and infrastructural aspects represents the tool to achieve the objective of sustainability and efficiency in the management and development of territories. Both ICT infrastructures and digital technologies have the mission to connect people and make them participate in the intelligent process.

As previously stated, the smart city model is characterized by a rich but fragmented theoretical framework, and by the absence of a shared practical foundation. There are indeed a few interesting international case studies such as Barcelona Smart City, but they are not enough to fill the abovementioned gaps.

To address the lack of a shared practical framework, since the 2000s some researchers at the University of Vienna have developed a classification system, ranking European medium-sized cities along six main axes: Smart Economy, Smart Mobility, Smart Environment, Smart People, Smart Life, Smart Governance [4]. Basically, the main objective of the proposed ranking system was to move from the theoretical to the practical dimension by using a scientific methodology that has been used and tested in other scientific fields. The objective of the intelligence ranking was not to rate cities to decree winners and losers but rather to define a set of criteria indicating the critical and higher potential aspects of the cities examined by implementing a series of actions (that mitigate the criticalities and improve the potential) with the goal of transforming a traditional urban context into a smart context.

The limitation of the University of Vienna's classification system lies in the restricted pool of cities selected. Focusing on studying medium-sized urban contexts is therefore applicable to a region/reality such as the European one in which the number of medium-sized cities is greater than the large ones and in which most of the population is leading a western lifestyle. It is difficult to transpose this system in a context like the Moroccan one, due to specific and different social, cultural, economic, and urban peculiarities. Adding to that the rural or hybrid urban/rural settlement in extreme climatic conditions exemplified by the case study proposed in this research.

3 The Model of the Frugal Smart City

Like all regions of the world, the Mediterranean region is not exempt from the typical problems of other places on earth such as pollution, drought, poverty, social differences, illiteracy, etc. Stratigea states that the immense cultural, landscape and religious heritage makes this slice of the world one of the most fascinating places but at the same time one of the most vulnerable [5].

Since ancient times, the cities of the Mediterranean have applied the principles of intelligence to manage their problems. Vianello asserts that the concept of intelligence is not new in the Mediterranean region and that past civilizations have always used the principles of "intelligence" to effectively manage their territories and impose their domination over the entire region. He states that: "The concept of intelligence in cities must be absolutely historicized. If we evaluate together parameters such as the effectiveness of forms of government, political and military power, economic power, the ability to radiate knowledge in the world, can we say that ancient Athens was not an intelligent city?" [6].

Cardellini also argues that the Mediterranean region has developed its own model of smart urban management over time and does not need to import development models from distant regions such as the United States, Northern Europe or East Asia. In an article on the digital platform forum.it, Cardellini states that: "You cannot plan an evolution or change thinking of lowering a winning model from above in other contexts. The tradition and culture of the Mediterranean imposes a completely different path to the smart city and in some ways opposite to that of the Northern European countries, a path that has people and especially creativity at its centre" [7].

The declination of the intelligent model in the Mediterranean space, emphasizes the importance of strengthening the intelligence in respect of the social, cultural and economic aspects of the Mediterranean space [8]. Some cities in the Mediterranean have been successfully using the digital urban model to manage their territories for years. The most interesting case concerns a city in the southern area of the

Mediterranean, namely the city of Casablanca, which has forged a new model of Smart City: The Frugal Smart City.

In the 1950s, Morocco gained its independence from France, and this has had an important consequence at the urban level. It brought an exponential and spontaneous growth of most Moroccan cities and Casablanca was no exception. The absence of an updated territorial organization scheme considering the new post-colonial socio-economic situation led to a chaotic development of the cities which in the 1970s had disastrous consequences, dysfunctions at all levels of the city and which concerned for example the lack of housing, inadequate and inefficient urban mobility systems, etc.

Starting in the 1980s, the region of Casablanca implemented the SDAU (Master Plan for Urban Development) to address the new issues facing the economic capital of the kingdom of Morocco. The city does not seem to have benefited from it as the phenomena of decrepitude and inefficiency show no sign of weakening. In 2013, local administrators in Casablanca decided to adopt a new urban development model, the smart city, creating in the process the first cluster called E-medina. The approach proposed by E-madina for the development of the Casablanca Smart City strategy was essentially based on the creation of a smart urban model that was both frugal and low-cost. The choice of a frugal approach stems from the fact that Casablanca, like most Moroccan cities, lacks the technological infrastructure and resources to develop high-tech projects. According to Prof. Hayar, president of the cluster and the medina, the frugal approach is recommendable because it takes into account the limited resources available in emerging countries like Morocco, the important thing is to match these limited resources with the benefits of technological advancement solutions proposed from the smart model [9]. It also states that the frugal Smart City "relies on mobiquitous (mobile and ubiquitous) ICT tools to provide useful services to citizens and collect data that will then be considered and analyzed to provide other, more appropriate services for the purpose of "sustainable and equitable overall social prosperity" [10].

4 Figuig, as a Prospect

4.1 Context

In order to expand the smart city model to other Moroccan realities, we had to choose a site that could challenge the limit of the concept. Figuig (Fig. 1), an oasis town situated in the east of Morocco on the border with Algeria appeared to be the best-suited candidate for the task. Figuig is comprised of seven Ksours (small fortified villages built of earth, characterized by compact urban structures and narrow streets) drowned in a palm grove of about 11,700 ha. At the door of the Sahara desert, this centuries-old town rich in its natural, agricultural and cultural resources

Fig. 1 The oasis town of Figuig in the Oriental region of Morocco

has suffered in the last decades territorial isolation, lack of economic opportunities, critical environmental and ecological problems, neglect of the heritage and depopulation.

4.2 Methodology

To grasp the complexity of this hybrid urban settlement in an arid zone, we had to rely on a multidimensional approach consisting of:

- Field work (survey and questionnaires).
- Residential collaborative multidisciplinary workshop.
- Meetings and presentations with local authorities and associations.
- Architectural and urban analysis.
- Literature review.

The gathered data served as the basis for the linear methodology adopted in this research (Fig. 2). The analysis brought up the criticalities specific to Figuig. Dichotomies were readjusted to fit the context of the study and then allowed the definition of principles of the frugal smart oasis according to the dimensions of the smart city model. These dimensions categorized the challenges in relation to the main criticalities identified upstream. Finally, all the above concurs in laying out concrete actions to be undertaken for the resolution of the challenges of Figuig to achieve the transition towards a frugal smart oasis. This last step is out of the scope of this paper and has not been discussed.

Fig. 2 The steps for a strategy for frugal smart oasis

4.3 The 4 Criticalities of Figuig

The extensive analysis allowed us to identify four main criticalities in the oasis town of Figuig, namely, Governance and social inclusion, urban realm, resources management and heritage. Each one of them impacts the city and its people.

- *Governance and social inclusion*: The town is confronted with enduring gender inequalities in accessing opportunities. The presence of a largely inactive female population in the political life and citizen associations impedes social progress. While on the hand, a very active network of citizen association proposes partnerships with various collaborators to implement various initiatives. This is witnessed by the launching of an international design competition for a new multi-functional urban center in the administrative town center; the Maison Oasis, which will function as a catalyst to engage the civil society.
- *Urban realm*: Our survey of the local population has shown that some parts of the oasis town, especially the new developments and the public spaces lack in lack identity and are often very fragmented and disconnected. They reproduce social fragmentation and are increasingly affected by overheating. The issue of climate and the lack of a comprehensive urban charter and tools to organize the public space have negatively impacted its liveability.
- *Resources management*: The oasis is alimented by a sophisticated traditional water system, a homogenous ensemble of water infrastructures, such as dams, cisterns, underground and overground canals. An age-old culture of water management has ensured the common use of a precious resource that is still today at the basis of the livelihood of the oasis. Unfortunately, Prolonged draught, overheating and unprecedented water evaporation are dramatically reducing the water level of underground cisterns and pools. It also threatens the survival of palm trees and dates cultivation, which in turn block the revitalization of the economic sectors or the creation of new innovative ones.

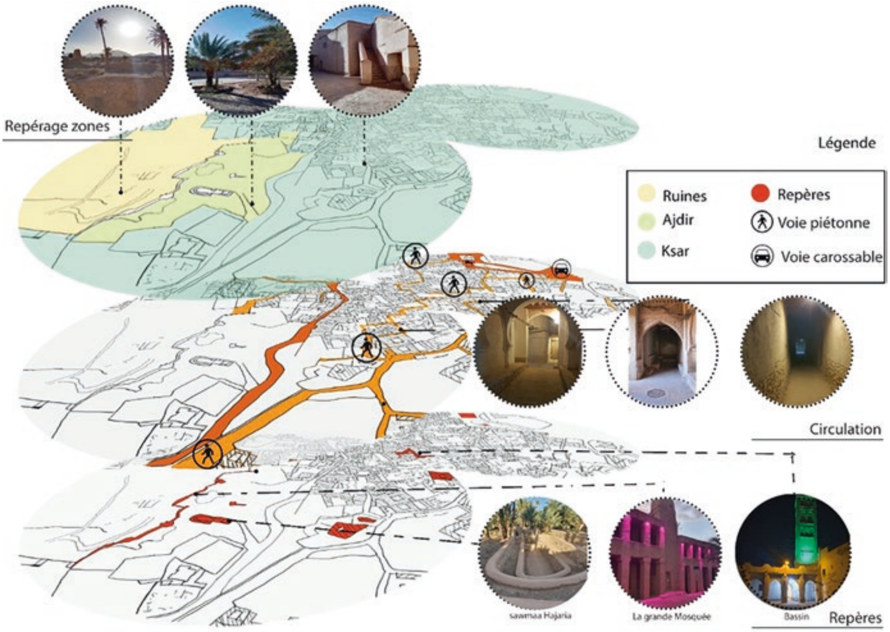

Fig. 3 Cultural built heritage sites to valorize in Ksar Loudaghir, Figuig

- *Heritage*: The unique cultural heritage of seven Ksars is the urban materialization of centuries-old social and cultural organization. Unfortunately, depopulation due to urban exodus threatens de material and immaterial built heritage (Fig. 3). The pervasiveness side of heritage in Figuig seems to us as one if not the most import challenges to tackle as it touches transversally all the others.

5 Frugal Smart OasiS: Definition and Principles

In order to define the Smart Frugal Oasis and above all an explicit framework of principles underlying this model, this research has been referred to the system by dichotomous of Bolici et al., as a methodology (which will obviously be adapted to what is context taken as a case study) has been dictated by the possibility of extrapolating a practical picture of the experiences of the case studies. Bolici et al. have analyzed a rich bibliography from which they have extrapolated 5 models and interpretative principles that can be summarized in 5 dichotomies. The main dichotomies examined in this analysis relate to approach, collaborative structure, intervention logic, technology level, and resources used in the smart process [11].

1. *Approach*: what role do technological and non-technological factors play in the transition to a digital and intelligent urban model.

2. *Development*: direction of smart actions, from the bottom-up, i.e. involving citizens, or from the top-down when the administration makes decisions independently.
3. *Collaborative structure*: i.e., the number and nature of actors involved and collaborating to define the strategy.
4. *Logic of intervention*: the scope of action can be unidimensional or multidimensional

Dimensions: (1) smart governance (2) Smart Economy (3) Smart Environment (4) Smart People

Building upon the aforementioned 4 dichotomies, we proposed to add 3 new ones based on our analysis of Figuig (Fig. 4). These dichotomies will subsequently lead to the formulation of the principles of the smart frugal oasis.

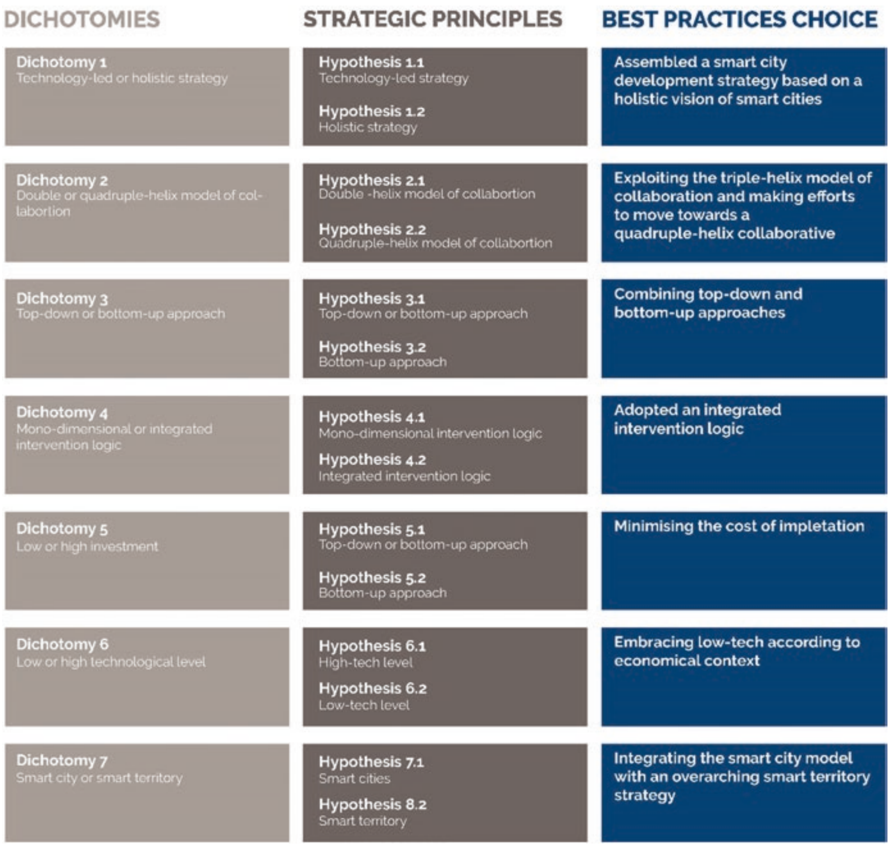

Fig. 4 Dichotomies, principles, and best practices choices of the frugal smart oasis based upon Bolici et al.

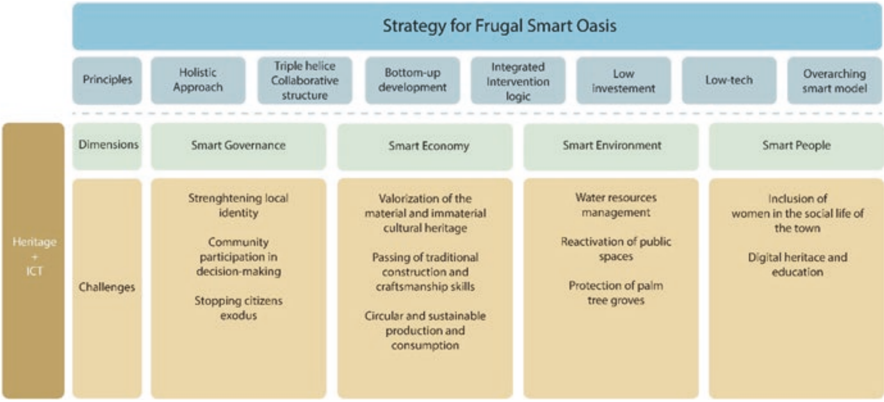

Fig. 5 Strategy for the frugal smart oasis

Definition of Frugal Smart Oasis A Frugal Smart Oasis is a smart, sustainable but above all resilient urban/rural context characterized by extreme climate conditions. The strategy of the Smart Frugal urban model is based on principles such as the holistic approach, the human centre, the multi-actors and a low-tech and low-cost intervention logic in which technology is an enabling factor and not the end.

The output of the research could be summarized in the diagram below (Fig. 5). It shows the principles extracted from the 7 dichotomies of the frugal smart city, which will guide all the subsequent decisions and pave the way to actions to be taken. The 5 dimensions of the smart city model as defined by the University of Vienna encompass the challenges that are identified from the criticalities plaguing the town. These dimensions of intervention are represented in silos transversally linked by the component that refers to information and communication technologies (ICT) and heritage.

The concept of the Smart Frugal Oasis and its overarching strategy has been presented to local stakeholders of Figuig during a presentation held on the 4th of June 2022. It was positively received, and the authors were asked to further develop their work into concrete scenarios for the oasis.

6 Conclusion

The paper expanded the notion of the smart city to oasis towns. A hybrid urban typology is located in an extreme environment. Figuig showed to be a great prospect which served as the foundation for the tentative definition of the frugal smart oasis. The outcome was the proposal of a strategy for the newly coined concept.

Future research will focus on developing concrete actions based on the principle identified in this paper to tackle the challenges identified in Figuig. Other paths could explore the robustness and the flexibility of the proposed strategy in other oasis towns in Africa and the MENA region. In the long-term, the creation of a transnational platform aimed at collaboration and knowledge dissemination for smart oasis towns.

References

1. Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology, 22*(1), 3–21. https://doi.org/10.1080/10630732.2014.942092
2. Dall'Ò, G. (2014). *Smart city, la rivoluzione intelligente delle città*. Il mulino.
3. Bolici, R., & Mora, L. (2015). Urban regeneration in the digital era: how to develop Smart City strategies in large European cities. *Techne. Journal of technology for Architecture and Environment*, 110–119. https://doi.org/10.13128/TECHNE-17507
4. Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Milanovic, N., & Meijers, E. (2007). *Smart cities - Ranking of European medium-sized cities*. Centre of Regional science.
5. Stratigea, A., Kyriakides, E., & Nicolaides, C. (Eds.). (2017). *Smart cities in the Mediterranean: Coping with sustainability objectives in small and medium-sized cities and Island communities*. Springer International Publishing. https://doi.org/10.1007/978-3-319-54558-5
6. Vianello, M. (2013). *Smart cities: gestire la complessit?? urbana nell'era di Internet*. Santarcangelo di Romagna.
7. Cardellini, M. troviamo-la-strada-per-la-smart-city-del-mediterraneo, *forumpa*. https://www.forumpa.it/citta-territori/troviamo-la-strada-per-la-smart-city-del-mediterraneo/. Accessed 03 Dec 2022.
8. Trombadore, A., Sala, M., Carta, M., & Basosi, R. (2015). *Mediterranean smart cities: innovazione tecnologica ed ecoefficienza nella gestione dei processi di trasformazione urbana*. Altralinea.
9. Hayar, A. (2015). Nouveau concept de Ville Intelligente Sociale et Frugale basé sur les services et réseaux mobiquitaires pour le développement économique et humain. *Organisation et Territoires, 1*, Art. no. 1. https://doi.org/10.48407/IMIST.PRSM/ot-n1.4034
10. Hayar, A., & Betis, G. (2017, September). Frugal social sustainable collaborative smart city casablanca paving the way towards building new concept for 'future smart cities by and for all. In *2017 Sensors Networks Smart and Emerging Technologies (SENSET)*, pp. 1–4. https://doi.org/10.1109/SENSET.2017.8305444
11. Mora, L., Bolici, R., & Deakin, M. (2017). The first two decades of smart-city research: A bibliometric analysis. *Journal of Urban Technology, 24*(1), 3–27. https://doi.org/10.1080/10630732.2017.1285123

A Simulation-Based Approach for Defining Energy Retrofit Strategies of Built Heritage Through the Use of H-Bim Tools

Stavroula Thravalou, Kristis Alexandrou, and Georgios Artopoulos

1 Introduction

Despite the lack of a regulatory framework for minimum energy performance requirements in historic dwellings, the potential for energy savings and emissions reduction by retrofitting the particular building stock has been widely acknowledged. This is achieved through the work of several research programs (e.g. SECHURBA, CLIMATE FOR CULTURE, 3ENCULT, RIBUILD, EFFESUS) [1–5] and studies [6–9]. The integration of dynamic Building Energy Simulation (BES) tools in the energy retrofitting workflow of buildings contributes to the development of an optimized renovation strategy and the implementation of cost-effective intervention solutions. Addressing the energy efficiency of built heritage through the means of BES has gained increasing interest among researchers over the last decades [6, 8, 10, 11]. As reported in the literature, the major limitations of BES in historic buildings concern (i) the lack of reliable thermo-physical data of envelope components, (ii) simplifications in the representation of geometric features (e.g., presence of thermal bridges) and (iii) the adoption of inaccurate models of certain physical phenomena, such as the decay of historical buildings [6, 12]. Understanding the assumptions that lie behind predictions of different software, allows for a more accurate and thorough understanding of a building's energy use and its associated costs and emissions.

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In parallel, Building Information Modeling (BIM) is an emerging process in the digitization and systematization of all the knowledge about the construction and operation of a given building, as it combines geometrical and alphanumerical information [13]. The BIM method involves the establishment of a collaborative data-sharing environment, enabling the organization and dissemination of models and documents among the actors involved. In this way, it improves transparency and reduces costs and resources; based on these capacities it is promoted by the initiative of the European Renovation Wave [14].

Despite the growing interest in the use of BIM technology, its implementation for the energy improvement of historic buildings is limited due to emerging technical complexities. Specifically, the challenges of Heritage Building Information Modeling (H-BIM) consist in the complexity of the geometry, i.e., vaults, domes, construction inconsistencies, ontologies for linked data regarding historical knowledge, provenance and conservation state. An additional challenge refers to inconsistencies and errors in data conversion from the BIM environment to BES software [15].

This paper presents a simulation-enabled workflow for energy and environmental improvement of historic buildings through the use of BIM. An attempt of integrating dynamic energy performance analysis in the Heritage Building Information Modeling (H-BIM) workflow highlights the data exchange and model definition-related challenges encountered in various steps of the process. This paper addresses specific knowledge regarding the modeling of historic buildings in a poor state of conservation or ruin condition.

2 Methodology

2.1 Overview of the Workflow

The main steps for the proposed workflow encompassing BES and H-BIM processes are summarized below:

- Building analysis and documentation;
- Creation of an H-BIM model;
- H-BIM model export and conversion for BES;
- Verification of the BES model;
- Optimization, sensitivity analysis and other design criteria;
- Interpretation of the results and selection of the energy retrofit strategy.

2.2 The Case-Study Building

Lessons learned and research results presented here were driven by the practical implementation of the method above for the study of real-world examples of built heritage that belongs to public authorities. This practice-led research method

Fig. 1 The case study building in Nicosia, Cyprus in: (a) 1934; (b) 2013; (c) 2019

enabled the authors to better evaluate the possible solutions to overcome challenges identified in the literature and faced in practice. The case-study building is located close to the medieval walls of Nicosia's historic center. It is a listed building and a unique example of Cypriot architectural heritage, as it combines features of colonial architecture (1878–1929) and urban vernacular architecture, e.g., the typological elements of the internal courtyard, along with covered semi-open spaces and a *portico* entrance hall [16, 17]. It was built in the second half of the nineteenth century as the club of the British cavalry and during the twentieth century, it was converted into barracks for the Danish-Canadian military detachment in Cyprus. The pilot building is currently in a ruin state with severe structural damages and collapsed building elements, caused by the lack of maintenance and the long-term abandonment (see Fig. 1). A deep renovation is in progress by the Municipality to reuse the building as a Municipal Folk Art Museum with the addition of approximately 120 m^2 of new spaces.

3 Building Analysis and Documentation

The first stage for the acquisition of the data and the development of the H-BIM model is *the Building Analysis and Documentation* which includes the following steps:

- Building survey, i.e., careful documentation of the building geometry, legislative information and other regulations.
- Heritage significance analysis: i.e., the study of historic layers, the assessment of the heritage significance and vulnerability to change and protection status.
- Conservation state analysis: i.e., report on construction materials, finishes, hygrothermal properties, decay phenomena and crack pattern analysis, identification of air leakage and moisture presence.
- Description of thermo-physical properties of the building envelope: i.e., the thickness of the walls, conductivity, density, specific heat, emissivity, infiltration rate and optical properties of glazed surfaces.

- Climatic analysis of the site: i.e., climatic and topographic conditions of the area, physical interaction with adjacent objects (e.g., building, trees etc.) and assessment of the inherent passive strategies with regard to the local microclimate.
- Energy audit: i.e., the gathering of technical information such as characteristics of the existing mechanical systems, the lighting and water systems, definition of the operational schedules of the building, i.e., internal gains, ventilation patterns, occupant behavior and heating/cooling systems (HVAC) set point.
- Indoor and outdoor environmental monitoring: user surveys and in-situ measurements of temperature, relative humidity, ventilation, solar radiation, thermal transmittance of the building envelope, etc.

In this stage, special attention is required for the definition of the thermal properties of single materials but also of the thermal transmittance (U-value) of envelope components, e.g., floors and walls. The extraction of core samples is an accurate method to identify: (i) the stratigraphy of the building envelope, (ii) the thickness and dimension of building components, as well as (iii) the thermal properties and moisture content of the building materials. However, in historic buildings where the extraction of building samples is not always possible, the use of the infrared thermography (IRT) and the heat flow meter (HFM) measurements are widely used. Furthermore, the definition of the operation schedules requires in situ record of this information through interviews and questionnaires submitted to the occupants or usage of reference values from international standards. It is noted that the temperature setpoint and the occupant's behavior are an important source of uncertainty in every building [18].

The method implemented here employed both traditional and innovative surveying techniques, i.e., topography, technical documentation as well as terrestrial laser scanning and photogrammetry. A number of different building materials and construction techniques (load-bearing stone walls, adobe walls, timber and lath) demonstrating various historic layers and construction phases were identified during the visual inspection of the site. As the building has been abandoned for many decades, the vast majority of windows and fenestrations are severely damaged or missing, yet there are a few airtight spaces that are still used as storage. The definition of the thermal transmittance (U-value) of the remaining stone masonries was conducted via HFM analysis. The underlying materials of the walls, rising dampness, as well as the emissivity of the original plasters, were also identified through IRT techniques, as shown in Fig. 2. Indoor and outdoor environmental monitoring was

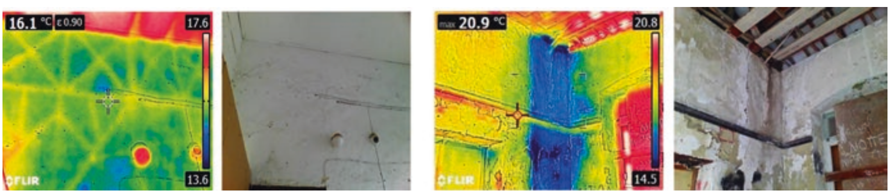

Fig. 2 Thermography performed in the case study building, identifying the timber wall construction (left) and the humidity resulting from water leakage from the roof (right)

also conducted. Yet, despite the necessary improvized interventions for assuring the airtightness of windows, e.g., closing considerable air gaps with duct tape, the in-situ measurements implicate a high level of uncertainty.

4 Creation of the H-Bim Model

BIM models can provide the basis of the energy model without additional modeling/remodeling efforts by the energy engineers, each and every time the design undergoes changes. However, depending on the Level of Detail (LoD), the resulting model may prove overwhelming for any analysis or simulation software. Many authors discuss the abstractions and simplifications that are performed in the translation process of BIM to BES models (i.e., in the transformation of the spatial geometry into thermal geometry), pointing out that only the absolutely necessary number of surfaces should ideally be created for BES [11]. Given the complexity of historical buildings, several simplifications have to be introduced, which in turn, represent uncertainties to take into account in the interpretation of the results. While curved geometry, for example, needs to be segmented into planar surfaces, the relationship between the number of segmentations and the accuracy of results needs further study [11]. Furthermore, variable patterns of decay on the same building component, as well as a considerable lack of standardization of the construction parts and dimensions, affect the thermophysical properties of heritage building envelopes, which have to be checked for accuracy with attention and critical thinking.

In the case-study building presented here, the modeling was assisted by a 3D point cloud produced by terrestrial photogrammetry documentation of both the inner and outer building surfaces. Autodesk Revit 2022 is used for the creation of the H-BIM model and the overall LoD used in the modeling was LoD 400. However, LoD 200 was applied in objects that have been severely damaged or removed, as their geometry was approximated based on historical documentation, i.e., historical photos. Urban-scale microclimatic parameters were also modeled, including surrounding buildings, trees and urban furniture.

5 H-BIM Model Export and Conversion for BES

In the next stage of this workflow, the detailed three-dimensional BIM geometry was converted and exported to the BES environment through the gbXML exchange schema. gbXML was selected as it is the only common data format compatible with the software combination used, namely, Autodesk Revit 2022 (BIM) and Design Builder v.7 (BES). The exported gbXML file was thoroughly evaluated in its geometrical consistency in the online gbXML Spider viewer platform, before importing to the BES environment. The geometry conversion evaluation loop proposed in the

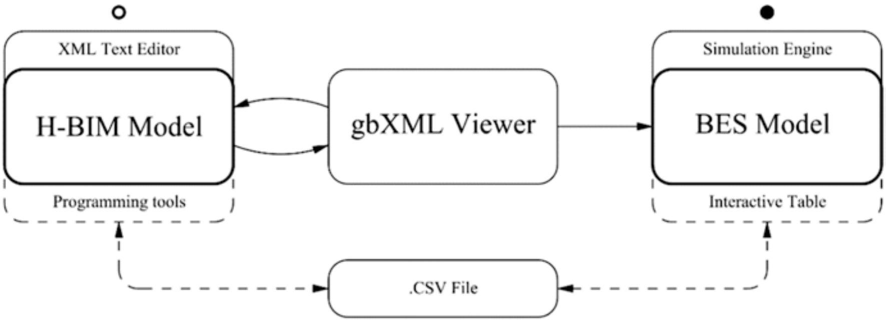

Fig. 3 Proposed BIM to BPS semi-automatic workflow

presented methodology is suggested by the authors to reduce any unnecessary manual post-processing efforts within the Design Builder environment. Several discrepancies have been identified, mainly regarding (a) the transparent envelope, (b) the differences in the walls' thickness, (c) complex wall construction systems and (d) the incorrect joint connection of walls and slabs. Building geometry was simplified to a certain level of abstraction that is necessary to perform the BES. The thermal properties of the building materials were added in the BIM library and assigned to the respective opaque multilayer elements. Opaque and transparent envelope elements (BIM nested families) have been configured as *schematic types* and linked to manually registered entries of the analytical properties pre-sets. Prior to exporting the file to the BES interface, an evaluation of the model's geometrical consistency to cope with the BES's planar surface model requirements was performed. The H-BIM model was further corrected through an iterative process until the appropriate planar surface generation was achieved. After importing the building model to the BES software, the *model data grid view* feature was used to display the imported data. The visible data (grid view) was then exported to a comma-separated file (.CSV) for subsequent editing. The file was accessed using the Dynamo plug-in and any missing values were added/substituted by the actual data located in the H-BIM model. The semi-automatic BIM to BES workflow is illustrated in Fig. 3.

6 Verification of the BES Model

Several simulation software is available for the evaluation of the energy performance of historic buildings [8]. According to a recent meta-study, EnergyPlus is used in half of the cases reported in the literature [11]. Despite the extensive use of numerical tools, and particularly whole building energy modeling and CFD software, numerous researchers have expressed concerns regarding the predictive accuracy of said tools. As representation models are a simplification of real-world

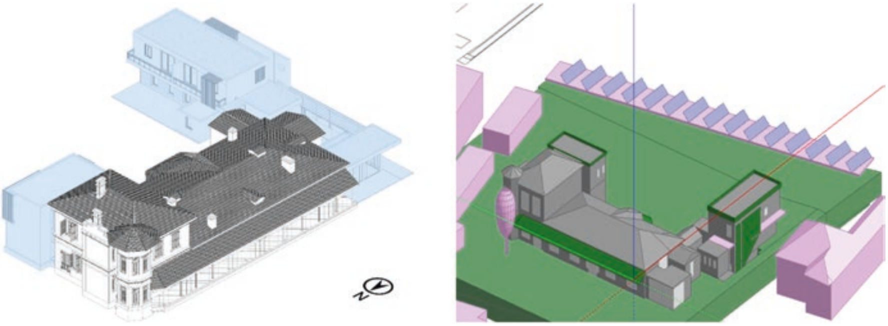

Fig. 4 Left: H-BIM Model in Autodesk Revit platform: North-West view of the base-case building; the original building that is restored (in white color) and the new additional spaces to be constructed (extensions in blue color); Right: BES model in Design Builder platform: South-West view of the proposed energy retrofit intervention with PV

conditions, the reliability of predictions provided by simulation models depends on the thoroughness of the calibration process [19]. A calibrated model can be further used for building diagnostics and control. Energy consumption data are generally adopted in the model validation process, however, in many cases, historic or vernacular buildings are naturally ventilated with no central HVAC systems, or they lack energy consumption data or any relevant information. For this reason, an increasing use of microclimatic parameters for calibration and validation purposes is reported in heritage BES [20]. This method also relies upon the use and availability of environmental data that are acquired typically through high-accuracy measurement campaigns.

In the case of ruined or abandoned buildings, as no energy consumption data can be retrieved, a base-case model is assumed to correspond to an airtight building. The operation schedules should be carefully defined by the authors following interviews with the future occupants of the building. For the definition of the temperature set-points, standard values may be used, according to the planned (future) use of each thermal zone. These steps were also followed in the case study buildings, assuming a base-case model with roof insulation, double glazing and operation schedules based on the proposed building use after its renovation, as shown in the left-hand side of Fig. 4. The heating, cooling and fresh air (ventilation) demands of the main areas of the building, e.g., exhibition spaces, offices, and reception, are fully covered by air-to-brine heat pumps (VRV/ VRF systems) with local heat reclaim ventilator (HRV/ VAM) units. The indoor and outdoor lighting demand of the building is planned to be supported by high-efficiency light-emitting diode (LED) light bulbs. A point of uncertainty in the projected occupancy study regarded the definition of the number of expected visitors, which increased the level of complexity in the design of general heating and cooling systems.

7 Sensitivity and Uncertainty Analysis, Optimization and Other Design Criteria

7.1 Optimization, Sensitivity and Uncertainty Analysis

As Peippo et al. [21] pointed out: "*Optimization procedures help the building designer and policy maker to come up with sound design solutions with the existing technologies, and consequently contribute to preserving the integrity of low energy building design practice*". Optimization techniques have considerably evolved in the last years, shifting to multi-objective optimization, with a strong preference for genetic algorithms [22]. The targets of an optimization study usually involve the environmental impact, the cost of the initial investment, the operational cost, as well as comfort criteria [22]. Optimization studies using whole building simulation software is a computationally demanding task. However, if a methodology of sensitivity and uncertainty analysis is applied in the early stages, it is possible to identify the most important parameters in relation to building performance and lead the optimization analysis in certain directions regarding the selection of the design variables. The aim of a sensitivity analysis is to discover the (typically few) input parameters to which the measured output of a model is sensitive. Conversely, in an uncertainty analysis, the variation in the input parameters is critical to the analysis, as the aim is to discover the likely variation in the output due to the actual variations in the input. A side effect of this is that the model may be sensitive to a specific parameter but, if the parameter is well known, it is not a critical parameter in an uncertainty analysis [12].

For the definition of the decisive design parameters in the case-study building, a sensitivity analysis was performed. The first set of input variables that were analyzed included 5 variables: (a) the roof construction (variable width of roof insulation), (b) Glazing type, (c) Cooling system seasonal CoP, (d) Cooling setpoint temperature and (e) Infiltration (ac/h). The output variable was Cooling electricity (Kwh). The results indicated that Cooling (Electric) is most strongly influenced by Cooling setpoint temperature.

7.2 Additional Selection Criteria for Energy Upgrade of Historic Buildings

According to relevant good practices, the assessment criteria for the selection of the energy improvement measures are not solely based on a risk-benefit scheme, but also respect the protection status of the dwelling, according to international conservation charters and principles [4, 19, 23]. In the presented workflow, the shared lessons learned regarding the final energy upgrade interventions cover the aspect of techno-economic feasibility, as well as the following:

- Compatibility and heritage significance: risks of architectural, aesthetic or visual impact, or risks regarding the building's setting.
- Technical compatibility and feasibility check: hygrothermal risks; structural risks; corrosion risks; salt reaction risks; biological risks; and reversibility.
- Environmental sustainability of the intervention: reduction of environmental pollution and emission of substances, use of renewable resources, recyclable/reused materials, low embodied energy.
- Other design criteria.

Moreover, the challenge of integrating Renewable Energy Sources (RES) technologies in a sensitive historic context consists in proposing reversible and compatible technologies that will increase the economic value and avoid any kind of conflict as defined above. For example, in the case-study building presented, emphasis was given to preserving the morphology and typology of heritage buildings, thus highlighting the principle of integrity in terms of material selection (The Venice Charter) [24], promoting interventions with reversibility and minimum impact on the authentic fabric (the Burra chapter) [25]. Moreover, since the design scenario involved the creation of a base-case model which corresponds to a building with enhanced energy performance, the main retrofit strategy for reducing carbon emissions was to mitigate fossil fuel electricity production by using RES. More specifically, solar power was introduced through the installation of Photovoltaic Panels (PV) on the roof of the parking shelter, i.e., decoupled from the main building structure, at the east part of the plot (Fig. 4 – right hand side) which would not obstruct the front elevation of the building. In this scenario, according to the BES results, the saved primary energy (expressed in budget reductions) using renewable energy would be 11.25 MWh, which corresponds to 54% of the calculated building's electricity needs.

8 Concluding Remarks

This paper provided an overview of the main challenges of defining an energy retrofit strategy through the use of a BIM to BES workflow. As multiple complex procedures with embedded uncertainties are involved (e.g., architectural documentation, environmental monitoring, energy auditing, dynamic simulation), the need for addressing carefully a methodological compromise has been pointed out. Despite the multi-level complexity of built heritage (geometric, material, conservation status and policy), which typically calls for a case-by-case approach to renovation, an agile and effective implementation of the proposed workflow advocates the importance of streamlining the data flow by means of predefined steps (e.g., guidelines of BIM exporting, verification of BES model, uncertainty analyses), and prescripted operations (e.g., data conversion).

Additionally, multi-objective optimization procedures may be very useful in supporting the design team to draft several potential energy retrofitting measures that meet the requirements of the considered objectives. However, besides energy and cost-effectiveness criteria, heritage buildings are subject to limitations regarding technical and architectural compatibility. The adoption of an integrated workflow, as presented through the implementation of this study, could provide the design team with a manageable number of design variables and performance results. The paper argues that this approach is more adaptive and effective for heritage building retrofit to make a final informed decision through feedback loops between modeling and simulation than typical approaches, where the designers are facing the challenge of exploring "manually" the available options within each scenario through a linear and static process.

Notably, the process of BIM to BES data exchange relies on a semi-automatic workflow (e.g., through the use of gbXML schema), while fully automated interoperability is still under development, and thus an accurate transitioning of the building geometry and metadata between software environments requires manual control and supervision. The integrated workflow presented here contributes to lessons learned and practical knowledge. The paper presented how this workflow can be employed as a decision-making tool for designing an energy retrofit strategy that is adapted to the specificities of built heritage, yet it has wider applicability in the existing building stock.

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References

1. De Santoli, L. (2015). Reprint of "Guidelines on energy efficiency of cultural heritage". *Energy and Buildings, 95*, 2–8. https://doi.org/10.1016/j.enbuild.2015.02.025
2. Historic England: Energy efficiency and historic buildings, how to improve energy efficiency. Historic England (2018).
3. D'Ambrosio, F. R., Mazzarella, L., Bellia, L., Filippi, M., De Santoli, L., & Romagnoni, P. (2018). *Energy efficiency in historic buildings*. https://www.rehva.eu/eshop/detail/energy-efficiency-in-historic-buildings
4. Green Building Council Italia. (2017). Manuale GBC Historic Buildings. In GBC Italia. https://gbcitalia.org/certificazione/gbc-historic-building/gbc-historic-building-documenti/
5. Troi, A., & Bastian, Z. (2015). Energy efficiency solutions for historic buildings. *A handbook*. Birkhauser, Basel.
6. Webb, A. L. (2017). Energy retrofits in historic and traditional buildings: A review of problems and methods. *Renewable and Sustainable Energy Reviews, 77*, 748–759. https://doi.org/10.1016/j.rser.2017.01.145

7. Laine, A., Davies, J., Buchanan, K., Warren, K., & Turtinen, J. (2019). *Heritage research matters*. Case studies of research impact contributing to sustainable development.
8. Martínez-Molina, A., Tort-Ausina, I., Cho, S., & Vivancos, J.-L. (2016). Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews, 61*, 70–85. https://doi.org/10.1016/j.rser.2016.03.018
9. Berg, F., Flyen, A.-C., Godbolt, Å. L., & Broström, T. (2017). User-driven energy efficiency in historic buildings: A review. *Journal of Cultural Heritage, 28*, 188–195. https://doi.org/10.1016/j.culher.2017.05.009
10. Cornaro, C., Puggioni, V. A., & Strollo, R. M. (2016). Dynamic simulation and on-site measurements for energy retrofit of complex historic buildings: Villa Mondragone case study. *Journal of Building Engineering, 6*, 17–28. https://doi.org/10.1016/j.jobe.2016.02.001
11. Akkurt, G. G., Aste, N., Borderon, J., Buda, A., Calzolari, M., Chung, D., Costanzo, V., Del Pero, C., Evola, G., Huerto-Cardenas, H. E., Leonforte, F., Lo Faro, A., Lucchi, E., Marletta, L., Nocera, F., Pracchi, V., & Turhan, C. (2020). Dynamic thermal and hygrometric simulation of historical buildings: Critical factors and possible solutions. *Renewable and Sustainable Energy Reviews, 118*, 109509. https://doi.org/10.1016/j.rser.2019.109509
12. MacDonald, I. A. (2002). *Quantifying the effects of uncertainty in building simulation.* [PhD Thesis]. University of Strathclyde.
13. ISO 19650. (2018). Organization and digitization of information about buildings and civil engineering works, including Building Information Modeling (BIM)—Information management using Building Information Modeling.
14. European Commission. (2020). Renovation Wave Strategy. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en
15. Calcerano, F., Thravalou, S., Martinelli, L., Alexandrou, K., Artopoulos, G., & Gigliarelli, E. (2023). Energy and environmental improvement of built heritage: HBIM simulation-based approach applied to nine Mediterranean case-studies. *Building Research & Information*, 1–23. https://doi.org/10.1080/09613218.2023.2204417
16. Demi, D. (1997). *The Walled City of Nicosia, A typology study*. UNDP United Nations Development Programme, Nicosia.
17. Thravalou, S., & Philokyprou, M. (2021). Urban design considerations in the environmental assessment of vernacular buildings with timber projections (sachnisi): The case of Nicosia's historic center. *Frontiers of Architectural Research, 10*(1), 176–189. https://doi.org/10.1016/j.foar.2020.11.001
18. Mahecha Zambrano, J., Filippi Oberegger, U., & Salvalai, G. (2021). Towards integrating occupant behaviour modelling in simulation-aided building design: Reasons, challenges and solutions. *Energy and Buildings, 253*, 111498. https://doi.org/10.1016/j.enbuild.2021.111498
19. ASHRAE. (2014). *Guildeline 14: Guideline 14, Measurement of energy and demand savings*.
20. Huerto-Cardenas, H. E., Leonforte, F., Aste, N., Del Pero, C., Evola, G., Costanzo, V., & Lucchi, E. (2020). Validation of dynamic hygrothermal simulation models for historical buildings: State of the art, research challenges and recommendations. *Building and Environment, 180*, 107081. https://doi.org/10.1016/j.buildenv.2020.107081
21. Peippo, K., Lund, P. D., & Vartiainen, E. (1999). Multivariate optimization of design trade-offs for solar low energy buildings. *Energy and Buildings, 29*, 189–205. https://doi.org/10.1016/S0378-7788(98)00055-3
22. Costa-Carrapiço, I., Raslan, R., & González, J. N. (2020). A systematic review of genetic algorithm-based multi-objective optimisation for building retrofitting strategies towards energy efficiency. *Energy and Buildings, 210*, 109690. https://doi.org/10.1016/j.enbuild.2019.109690
23. CEN 16883:2017 Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings. (2017).
24. ICOMOS. (1964). International Charter for Conservation and Restoration of Monuments and Sites (The Venice Charter).
25. ICOMOS. (1999). The Australia ICOMOS Charter for the Conservation of Places of Cultural Significance (The Burra Charter).

Generative Environmental Design Tools to Support Circular Economy at the Local Scale

Matteo Clementi and Leonardo Belladelli

1 Introduction

The insights presented in the paper show the main features of tools oriented to develop a self-sustainability scenario, with the intention of identifying possible synergies between carbon-neutral scenarios and the ones oriented to boost local circular economy process consistent with the goals of a generative environmental design. This paper focuses on the potential use of Free and Open Source (FOS) GIS and open data in order to develop support maps for Generative Environmental Design processes.

GED assigns to the project the role of the interface in the management of dynamics that are consistent with the regenerative cycles of the natural ecosystems involved, consequently GED involves knowledge of:

- The general features of the local ecosystems.
- The main players in the system.
- The flows of energy and matter exchanged between them.

GED, starting from the awareness of the strategies normally used by a natural ecosystem in the evolutionary process (goal functions) [3], is mainly oriented towards the integrated design management of the main dynamics that characterize the territorial area of reference with the twofold goal:

- Maximize the amount of local solar energy useful for carrying out work [2], in the specific case of the anthropized environment, useful for carrying out the main

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activities that characterize the local territorial metabolism, reside and work, nourish and clean, transport and communicate [4].

- Ensure matter circularity to the maximum possible extent. In fact, the inclusion of anthropogenic dynamics in natural dynamics implies the maintenance of the balance between the flows and stocks of production and consumption.

Both goals call into question the awareness of the main dynamics relating to local consumption activities and the resources available locally. In particular, the first asks us to verify how much of the solar energy incident in a territorial area defined as local is directly involved in satisfying the local demand for energy and matter.

The second refers to the possibility of understanding and increasing the possibility of locally closing the production, consumption and regeneration cycles associated with the use of the materials. In particular, the second goal provides for full compatibility between the regenerative cycles of local ecosystems and the dynamics relating to the local anthropized system, consistent with the principles of the Generative economy [1]. In order for this to be possible, the text introduces the potential for using thematic maps such as geographies of resources and geographies of impacts in making choices consistent with the GED [5]. These tools use open source and open data sw, in particular Geographic Information Systems, with the aim of representing and quantifying information relating to the demand for energy and matter associated with the established community (Geographies of the impacts) and the supply of energy and matter relating to the 'local territorial scope (geographies of resources).

The experimentation of these tools aims to support the pursuit of the themes of the PGT that strictly refer to the implementation of carbon-neutral strategies [6]. The term PGT stands for the Italian acronym for Territorial Governance Plan, the tool that regulates building activity within the municipality of Milan.

The paper summarizes some of the results of ongoing research, applying the method to a portion of the urban fabric of the Chiaravalle district in Milan.

The area under consideration is the portion of the urban fabric that delimits the southeastern part of the Milan municipality near the Southern Agricultural Park of Milan, in particular the Vettabbia Park. A small settlement that hosts about 1000 inhabitants near the abbey of Chiaravalle.

2 Introductory Notes on the Territorial Governance Plan (Pgt)

An approach oriented to regenerative planning foresees an attitude of the designer and of the political decision-maker oriented not only to maintain the cycles of local ecosystems but to improve their functioning. The Territorial Governance Plan approved in 2019 by the Municipality of Milan approaches this strategy by adopting some simplifications in order to make the law applicable immediately. The initiatives promoted refer to the accounting of carbon flows and water management in order to associate energy-saving strategies with reactivation strategies of local natural ecosystems. In particular, the PGT goals are aimed at ensuring that the building interventions subject to authorization are aimed at reducing and balancing CO_2 emissions and at the same time improving the functioning of local ecosystems. This second goal is achieved through the creation of incentives that favour the increase of vegetated and permeable surfaces and at the same time the creation of new green areas financed with compensation processes. These compensation processes are adopted if the building design does not comply with the requirements imposed by the law and are aimed at financing projects within the municipal area with the aim of enhancing local natural ecosystems. The inclusion of new renaturalized areas provides the opportunity to increase the networks of relationships and also to encourage the involvement of the inhabitants and the flows managed by their activities in the dynamics of local ecosystems. While such strategies would increase local circular flows of matter on the one hand, on the other hand, it would give the opportunity to associate strategies for emission reduction to the involvement of local manpower in these regenerative processes. The development of new figures oriented to the direct involvement of the population living in the same place, such as community cooperatives, allows to promote civic engagement processes by creating local circular micro-economies around the management of regenerative and sustainable planning processes.

This text explores the possibilities offered by thematic maps created with FOS software and open data in the quantification and communication of such information with the aim of supporting strategies oriented to carbon-neutral scenarios. In particular, it does so starting from what has already been proposed within the PGT with the intention of understanding how these thematic maps can support the strategies promoted in the PGT and at the same time support administrations and designers in identifying systemic aspects that can support the triggering of local micro-economies based on the regenerative cycles of sustainable territorial metabolism.

The themes of the PGT that strictly refer to the implementation of carbon-neutral strategies applied to new and existing buildings are:

1. Solutions with high-energy performance
2. Renaturalization interventions
3. Technologies for reduced water consumption and for the reuse of rainwater
4. Use of sustainable and / or recycled content materials
5. Adoption of surface finishes with a high solar reflectance coefficient (Floors, Roofs)
6. Solutions for sustainable mobility

The following paragraphs illustrate how thematic maps developed with open source and local open data GIS sw can support the application of these strategies. The sw used for the main processing are: Quantum GIS (https://www.qgis.org), GRASSGis (https://grass.osgeo.org).

3 Tools to Support the Choice of High-Energy Performance Solutions

The following is part of this set of strategies:

- All interventions related to increasing the energy performance of the opaque and transparent envelope;
- Interventions on improving the energy efficiency of thermal systems;
- The installation of devices for the production of energy from renewable sources.

FOS GIS and open data can support the first and third set of strategies, in particular, namely "interventions related to increasing the energy performance of the opaque and transparent envelope" and "the installation of devices for the production of energy from renewable sources". As regards the first, it is possible to map data relating to the shape of the building useful for estimating the energy needs of the building and for a summary assessment of the possibilities of intervention on the building envelope. Starting from the data relating to the aerial photogrammetric survey of the built urban area, made available by the Municipality of Milan, it is possible to associate specific indicators to the polygons relating to the individual buildings, summarizing information on the geometry of the building and urban form [7].

This information, together with what has been made available by Istat (the Italian National Institute of Statistics) [8] relating to the population and housing census, allows for a preliminary assessment of energy consumption and, in the hypothesis of use of natural gas, the related CO_2 emissions and to publish such information in thematic maps to support political decision-makers and the designers. Those data can be associated with three different spatial scales using GIS:

- The volumetric unit of the buildings, or the polygon representative of the profile of a portion of the building characterized by the same eaves height.
- The building, the ground profile of a single building that includes multiple volumetric units.
- The census section, a portion of urbanized territory that includes both buildings and open spaces and constitutes the highest resolution at which the open census data on population, housing, industries and facilities are made available.

3.1 Maps on Building Shape Indicators to Assess Energy Needs

Starting from what has been published and can be read and processed through FOS GIS, it is possible to create specific thematic maps that publish significant data on the shape of buildings and the relationships between them and open spaces (Fig. 1):

Fig. 1 Satellite view of the Chiaravalle district (source: Google Satellite), in the southern part of the municipality of Milan, superimposed on the geometry of the census blocks

- The surfaces exposed to the outside, compared to those shared between different buildings and then map building shape indicators such as the Surface / Volume ratio.
- The combination of this information with data relating to the number of inhabitants associated with the census section makes it possible to map the availability of surfaces per person for each census section to estimate the per capita weight of building efficiency measures [9].

3.2 Maps on Local Availability of Solar Energy

The availability of information relating to the height of the volumetric units of the buildings together with the data relating to the orography of the terrain allows you to use FOS GIS to create a high-resolution Digital Elevation Model. These are raster maps in which a pixel corresponds to a square surface of 0.5 m side which represents in the form of gray tones the different heights of the artifacts present in the analysed urban area. Starting from this model it is possible to represent particular shape indicators or the Sky view factor and then proceed with the mapping of the incident solar radiation. This processing allows to create various types of thematic maps (Figs. 2 and 3):

- Mapping of solar radiation on the horizontal plane to associate production capacities with the building's rooftops.
- Mapping of solar radiation on the horizontal plane, at different heights from the ground, to estimate the possibility of installing solar collection devices on the building's facades.
- Mapping of solar radiation on open spaces.

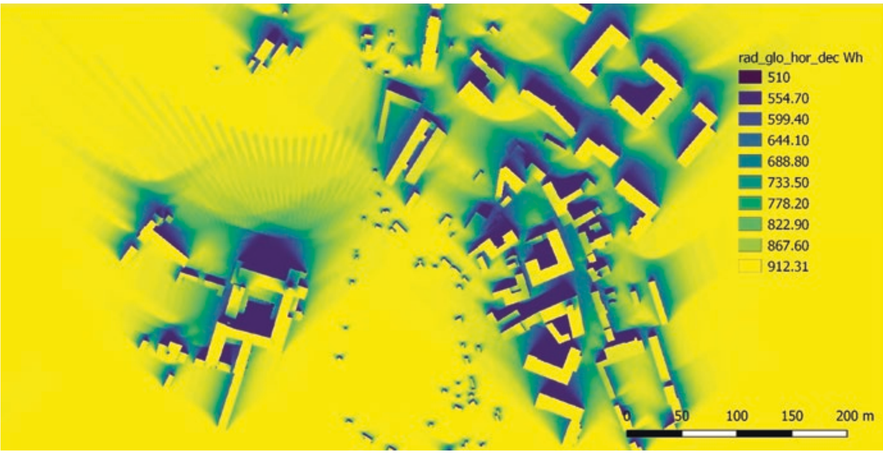

Fig. 2 Global solar irradiation map processed on a 1 pixel / 0.5 m resolution DEM, relative to the average day of December

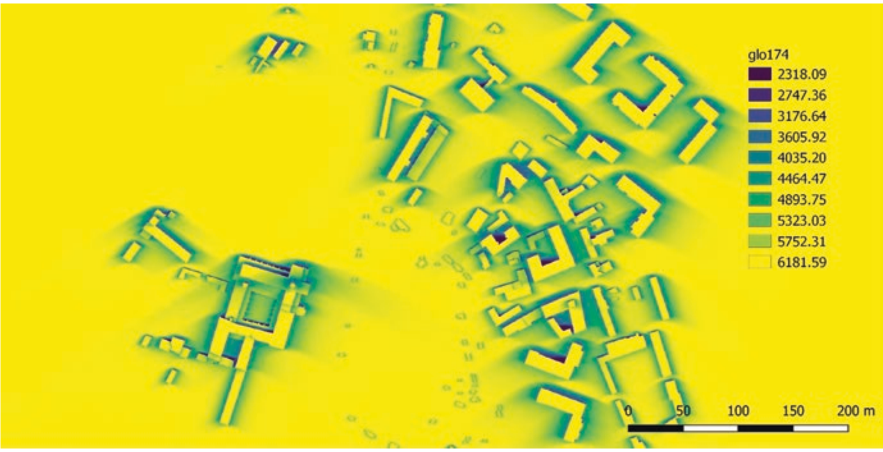

Fig. 3 Map of global solar irradiation processed on a 1 pixel / 0.5 m resolution DEM, relative to the average day of June

4 Tools to Support the Choice of Renaturalization Interventions

The mapping of solar radiation on the ground, on the roofs and on the facades can support the choice of herbaceous or tree species to be cultivated and the effective possibility of absorbing CO_2 based on the available energy. To facilitate the application of this strategy in the PGT, the green vegetated surface is currently associated with the ability to absorb annually 6 kg of CO_2 per square meter and a tree with 50 kg of CO_2. Indeed, this capacity depends on the size of trees, the availability of

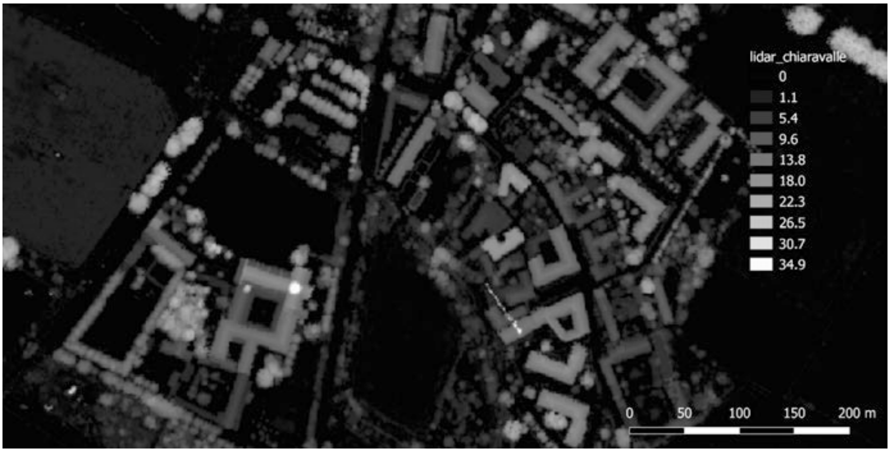

Fig. 4 Portion of the lidar survey relating to the Chiaravalle area, the resolution is equal to 1 pixel / m^2

solar energy as well as on the availability of water and nutrients. Useful information on the geometric configuration of the trees can be mapped through the use of lidar surveys made available on the national geoportal, the resolution level of the surveys is equal to 1 pixel / m^2 [10] (Fig. 4).

4.1 Maps on Local Availability of Green Biomass

The information made available allows you to check the actual volume of existing trees and to develop solar radiation maps that take into account their geometric configuration. The installation of new vegetated areas can be supported by information relating to solar radiation and possible relationships with existing vegetation. The mapping of solar radiation conducted starting from these surveys (Figs. 5 and 6) also allows to identify of possible areas suitable for urban agricultural production, from planting fruit trees, installing productive green walls, rooftop agriculture devices and other urban agriculture interventions that can favor the start-up of local productive activities.

4.2 Maps on Local Availability of Rain Water

The amount of rainwater incident monthly on roofs and open spaces represents important information in the choice of low energy-consuming strategies oriented not to use drinking water from the aqueduct. Making this information available requires associating information relating to the quantity of rain incidents monthly

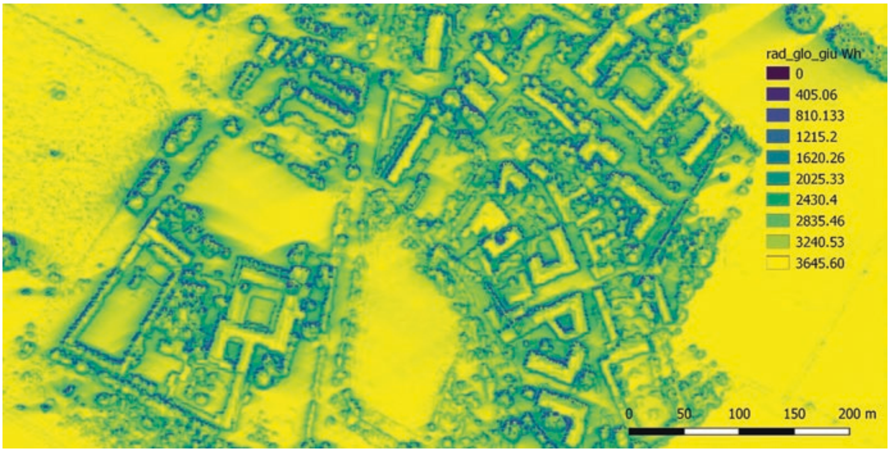

Fig. 5 Map of global solar irradiation processed on a 1 pixel / 1 m^2 lidar survey, relative to the average day of September

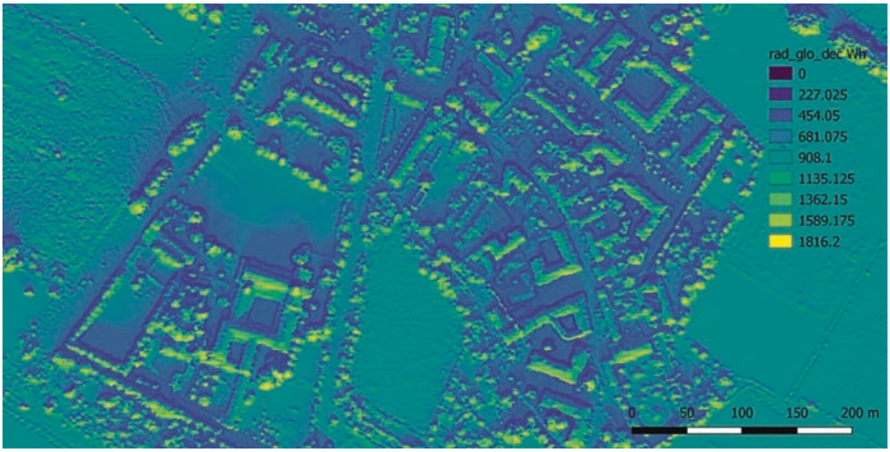

Fig. 6 Map of global solar irradiation processed on a 1 pixel / 1 m^2 lidar survey, relative to the average day of February

and annually on the roofs and to the geometric data made available by the aerial photogrammetric survey relating to buildings and open spaces. This climatic data is made available by the local municipality and ARPA (Regional Environment Protection Agency) and refers to data representative of the annual average and data relating to extreme events (representative of the possibility that an extreme event occurs in a multi-year interval of time usually 20, 50 or 100 years). In the case of the data referring to the monthly average, the open data portal of the municipality of Milan reports the monthly average of the atmospheric precipitation values [11]. The data show an average annual quantity equal to 1006 mm, with monthly average values that fluctuate depending on the month from 50 mm in August to 100 mm in April, with the exception of November where values around 170 mm are recorded.

4.3 Maps on the Amount of Carbon and Nitrogen Emitted Through Organic Waste

Another aspect in which a systemic approach to design favours the implementation of carbon-neutral strategies is related to the possibility of locally producing nutrients. Buildings regularly export nutrients in the form of metabolic waste and organic waste. In the second case, the local treatment of the green component of organic waste would provide a contribution to the ability of local ecosystems to absorb CO_2, both in the soil and in the metabolic activity of plants [12]. Starting from the number of inhabitants associated in with the census block, it is possible to map the potentially emitted flows of organic waste and therefore of the relative nutrients (starting from carbon and nitrogen flows).

5 Tools to Support the Applications of Technologies to Reduce Water Consumption and for the Reuse of Rainwater

The mapping of the availability of rainwater makes it possible to use these flows not only for irrigation but also to reduce the consumption of drinking water from the aqueduct. To understand the precise effectiveness of this solution it is important to compare the capture capacities of roofs and waterproof open spaces with the mapping of water consumption per building. These types of maps can be elaborated starting from the number and characteristics of the inhabitants associated with each census block.

6 Tools to Support the Use of Sustainable or Recycled Materials

The possibility of locally producing sustainable or recycled materials that can be used in construction presupposes the mapping of possible emission flows of waste material from local production and residential activities. This availability of information could give rise to local collection and processing workshops. Among municipal solid waste, paper and textile waste could find use as building insulating material together with straw produced by peri-urban agricultural activities. Polymeric materials would find an interesting use in the construction of support devices for urban agriculture (for example tanks for cultivation and water storage).

Another material available as waste material in suburban urban areas is the decommissioned polymeric sheets of street advertising, the mapping of possible emission flows could trigger the installation of light shading systems characterized by high reflectance finishes, one of the possible strategies promoted in PGT.

7 Tools to Support Strategies for Sustainable Mobility

The thematic maps to support the application of these strategies at the current level of development include.

the availability of open spaces per person in the different census blocks (for bike parking and mobility). The reduction of CO_2 emissions is in fact correlated to the per capita reduction of daily impacts and quantified in terms of avoided kilometres, a significant data is the availability of parking spaces per person. If these spaces coincide with those most affected by solar radiation then they could be suitable for the installation of photovoltaic canopies or photovoltaic pergolas suitable for generating shade and at the same time producing electricity for mobility.

8 Conclusion

The coexistence of the same GIS of different types of information, through the thematic maps developed to date and under development, has revealed the usefulness of associating the data relating to the local territorial metabolism to the census blocks. The information relating to the local supply of energy and matter and to the local demand finds in the quantification per person a functional unit of reference capable of carrying out trans-scalar balances, both at the block scale, represented by the boundaries of the census blocks, and at a larger scale through the aggregation of the data associated with each block. Table 1 shows some of the information associated with the different census blocks and related to quantities per person. A fundamental condition for local micro-economies to be activated is the possibility of intercepting existing spending flows, these dynamics are activated in the first place by the daily life of the established community, for example by the expenses for winter heating, together with the expenses for transport and food supply. The intention to intercept local spending flows further opens up the possibilities of intervention to reduce CO_2 emissions linked to lifestyle, giving the possibility to act on buildings and open spaces to reduce the energy consumption of buildings but at the same time reduce the impacts of mobility and nutrition. In the latter case, the design of the vegetated spaces plays multiple role; on the one hand, it favors the absorption of CO_2, and on the other it lends itself to the activation of local production/consumption flows that can be promoted by local cooperatives, oriented towards the local management of nutrients and local food production.

Table 1 Some of the per capita quantities supporting the design choices and associated with the different census blocks of the Chiaravalle district

n_census blocks	2737	2738	2739	2740
Rooftop area m^2/person	22,90	21,70	12,66	240,31
Outdoor area m^2/person	500,92	63,29	99,80	2542,91
Outdoor area without trees m^2/person	351,00	39,83	59,05	1660,71
Sol rad June rooftop kWh/person	141,50	134,09	78,23	1485,14
Sol rad Dec rooftop kWh/person	20,84	19,74	11,52	218,69
Sol rad June outoor lidar kWh/person	1143,24	119,49	173,97	5184,47
Sol rad Dec outdoor lidar kWh/person	268,99	28,15	40,96	1214,25
Trees volume m^3/person	1124,98	131,47	212,62	7883,85
Rainwater rooftop year m^3/person	23,05	21,84	12,74	241,90
Rainwater rooftop June m^3/person	1,83	1,73	1,01	19,20
Rainwater rooftop Dec m^3/person	1,80	1,71	1,00	18,94

References

1. Kelly, M. (2012). *Owning our future*. Berrett-Koehler Publishers.
2. Odum, H. T. (1996). *Environmental accounting, energy and environmental decision making*. John Wiley & Sons.
3. Fath, B. D., Patten, B. C., & Choi, J. S. (2001). Complementarity of ecological goal functions. *Journal of Theoretical Biology, 208*(4), 493–506.
4. Baccini, P., & Brunner, P. H. (2012). *Metabolism of the anthroposphere: Analysis, evaluation, design* (2nd ed.). MIT Press.
5. Clementi, M., Fontana, C., & Rogora A. (2018). Open Network for local self sustainability, boosting bioregional development through an open data sharing system. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-4/W8, 27–33.
6. Comune di Milano. (2020). Piano di Governo del Territorio. Piano delle regole - Norme di attuazione. Art.10 - Sostenibilità Ambientale e Resilienza Urbana.
7. Comune di Milano. (2022). Data available at the following link: https://geoportale.comune.milano.it/sit/, data accessed on March 2022.
8. ISTAT, Italian National Institute of Statistics. (2022). Data available at the following link: www.istat.it, data accessed on March 2022.
9. Morganti, M., Clementi, M., & Rogora, A. (2021). Open-source integrated mapping of urban form and solar radiation for environmental design. In J. Littlewood, R. J. Howlett, & L. C. Jain (Eds.), *Sustainability in energy and buildings 2021* (pp. 377–386). Springer Nature.
10. National Geoportal. (2021). Data available at the following link: http://www.pcn.minambiente.it/ data requested on February 2021.
11. Comune di Milano. (2021). Data available at the following link: https://dati.comune.milano.it/dataset/ds306-ambientemeteo-precipitazioni-mese-2008-2014 [Online], data accessed on December 2021.
12. Chrisoulakis, N. (2015). *Understanding urban metabolism*. Earthscan.

An Integrated Approach for Energy and Environmental Improvement of Built Heritage Through Building Information Modeling (BIM)

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1 Introduction

Energy consumption and climate change represent two of the main current international challenges and are an issue for built heritage as well, in terms of aggressive environments toward buildings, risk assessment from the macroscopic impacts of climate change and, due to higher energy cost, risk in terms of reduced usage of buildings, which is the most important factor to ensure their conservation. Historical buildings are not the most numerous nor energy-intensive portion of the building stock, thanks to their natural passive behavior optimized for their reference climate [1]; however, climate change is weakening this assumption with significant consequences for their energy consumption, the comfort of their occupants and conservation, thus urging the built heritage community to mobilize.

The concept of sustainable development as a basic principle of social action was introduced by the Brundtland report to the United Nations General Assembly in 1987 [2] and it was divided into three dimensions (economic, environmental and social), focusing on their balancing, in order to pass on a liveable world to the future generations. This initial approach evolved over the years thanks to the United Nations and the work of its Intergovernmental Panel on Climate Change (IPCC), aimed at providing the world with scientific information relevant to understanding the basis of the risk of climate change, its impacts and possible responses. The drafting of IPCC reports, since the first in 1990 [3] reviewed in 1992, [4], served as the basis for the United Nations Framework Convention on Climate Change and as a support for global agreements, among which the most important were:

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- The Rio declaration [5], that aimed at reducing greenhouse gas emissions without imposing mandatory limits, but nevertheless envisaging to hold successive conferences of parties (COP) to produce further and mandatory deeds.
- The COP3 Kyoto protocol, which introduced a legally binding treaty, committing signatory countries (representing initially about 18% of global emissions, AA. VV. [6]) to reduce emissions by an average of 5% compared to the 1990 levels in the period 2008–2012.
- the COP21 Paris agreement, a new global action to hold the global average temperature increase below 2 °C above pre-industrial levels and to increase the adaptation capability to climate change impacts, fostering climate resilience and reducing greenhouse gas emissions, also through economic support to these measures.

The concept of sustainability reached a milestone with the 2030 Agenda [7] and its 17 Sustainable Development Goals (SDGs), which, although unprecedented in scale and target achievement (eradicating poverty and achieving sustainable development by 2030 worldwide), provided a shared global vision and local applicability. This was achieved by taking into account both national realities and local context and challenges, including a strong follow-up mechanism [8] and defining a series of specific measurable and achievable objectives [7, 9]. In 2020, the European Commission also launched the New European Bauhaus, an initiative that emphasizes sustainability as a central element, and beauty and inclusion to rethink cities, making them more liveable, functional and accessible to all. Within this framework, cultural heritage represents a key asset for most of the 17 SDGs [10] and is being increasingly recognized as a fundamental driver for achieving its objectives [10–13]. One of the most advanced documents of this recognition is the Cultural Heritage Green Paper, developed by the most important stakeholders of the heritage sector reunited in the Climate Heritage Network, in response to the European Green Deal somewhat missing the mark on heritage [13]. The focus point of the document is that cultural heritage has a central role in the change envisioned by the EU Green Deal and should be considered more as a resource and less as an obstacle [14]. Among the most interesting statements, there is the potential of cultural heritage to involve citizens in the challenge of decarbonization and the professional upskill required for cultural heritage experts to take on the fight against climate change. More in detail, the chapter on historical buildings refers to the Renovation Wave [15], proposing built heritage as a driver to reach the objectives of the European Green Deal, with specific recommendations like: the principle of energy efficiency first; the revision of the Energy Performance Building Directive to include built heritage and the related approaches; the use of incentives to support the regulation, with specific mechanism for built heritage owners; the upskill of experts to support these interventions; the implementation of 100 demonstrators; the inclusion of the heritage sector within the high level forum of Architectural Engineering and Construction sector [14]; an attention to themes also shared by the EU Open Method of Coordination (OMC) group of Member States' experts on 'Strengthening cultural heritage resilience for climate change [13].

2 Toward a New Sensitivity in Built Heritage Conservation

The first step toward the new role of built heritage in the fight against climate change was achieved at a theoretical level through a process of disciplinary cross-fertilization between the conservation theory and the environmental design theory, of which the Italian scientific debate can show a bright example. Both disciplines are characterized by the need for a scientific approach to design, by an interdisciplinary point of view with holistic, multiscalar and systemic methodologies and by a time perspective that spans different generations [1]. However, their integration has not been smooth, also due to a delay in legislation (that we are still experiencing, by looking at the EPBD proposal of revision, EC [16]), especially when the economic pressure of the construction sector risks turn the issue of energy efficiency into a trojan horse for poorly controlled interventions on prestigious historic buildings. The seed for the switch toward a cross-fertilization of the two disciplines was identified by the scholar Giovanni Carbonara in the field of structural consolidation, where the historicization of the technical-technological operations, by putting them into a context of critical-technical reasoning [17] within the framework of critical restoration [18], allowed the development of a scientific approach. Although being less abstract and mathematical compared to the previously used methods to study ancient wall structures, this approach was not less rational or scientific, entailing a deeper comprehension of their functioning. Just as, for the consolidation of historical structures, the concept of improvement, as opposed to simple regulatory compliance, sparked a new era of good interventions, similarly, in the field of energy efficiency, the same principle has allowed to overcome the diffidence among experts and started an interdisciplinary dialogue that can support better interventions and offers at least four fundamental advantages to the scientific debate and technological application.

The first advantage is the interdisciplinary cross-fertilization in itself. Although the dialectical and interdisciplinary relationship between science, technology and restoration can be traced back at least to the Athens charter [19], the reductionist tendency to obtain an understanding of a complex object by studying its parts in isolation [20] constitutes a fundamental limitation in the field of restoration, in particular when a deterministically technical vision tends to overshadow more and more the critical historical contribution, up to the point of indirectly considering it useless. The reflection of the Scholar Liliana Grassi, however, suggests that cross-fertilization is not about defining a hierarchy of skills, but it is about giving theoretical formulation to the technological problem in the field of conservation [21]. This can be obtained by refusing a strong separation between cultural and technical aspects [21, 22], as demonstrated by the benefits that a critical perspective gave to the discipline, for example eliciting the criterion of homogeneity between the original static system and the intervention model, between ancient structures and modern additions, between traditional and innovative materials, ensuring greater compatibility and continuity of behavior to the entire building [23]. This reflection is extremely useful also in the environmental design field, as it can be considered like a compass for guiding the analysis every time the study of a building faces a knowledge problem that requires the use of field instruments or simulation methods, which struggle to work with the heterogeneity and complexity of the historical material. These are situations where a methodological compromise must be reached among procedures that, despite their limits, represent the best possible rational formulation of the knowledge problem on the basis of data, hypothesis and interpretation [24, 25].

The second advantage is the knowledge base for sustainability [13] provided by built heritage even for new construction, thanks to its awareness of the reference climate: a wealth of knowledge and methodologies that can also enrich the reasoning on built heritage conservation and decay phenomena (strongly affected, for example, by wind and sun exposure).

The third advantage comes from the emphasis that the EU directive 2010/31 [26] poses on the role of public administration as an example of the energy efficiency of the construction sector, and the role of historical buildings as symbols of European cities, if not of Europe itself, which confirms cultural heritage as a fundamental driver for its ability to involve citizens in the processes of ecological transition. This point of view is also stressed by the importance of promoting lighthouse demonstrator projects [13, 14].

The fourth advantage is the technological stress test that built heritage represents for environmental design methodologies. As demonstrated by several research projects [1, 27–30] but also by a few guidelines [31, 32], that tackled the issue from a much more operative point of view, the complexities related to those interventions makes built heritage the most demanding experimental laboratory ever to test new technologies and approaches and their scalability, and this requires also a continuous upskill of involved professionals and stakeholders [13, 14]. The maturation of this cross-fertilization process and of a new sensitivity among stakeholders on the energy and environmental improvement interventions of historic buildings is also supported by the integration of advanced digital technologies to support the whole process, namely Building Information Modeling (BIM) and Building Performance Simulation (BPS).

3 BPS and BIM Support to Energy and Environmental Improvement Intervention

BPS is among the most powerful tools to support the energy-efficient design of buildings. BPS is based on a behavioral model of a building at a given stage of its development, to study its energy and environmental performance from both comfort and energy consumption perspectives [33]. The main advantage of a simulation-based approach is to treat the building as an integrated system of optimizable elements instead of the sum of elements to be designed and optimized separately [34]. This provides decision support for environmentally and energy-efficient design solutions [35], producing relatively rapid feedback on the performance implications of the design hypotheses and allowing the exploration of design solutions, targeting performance objectives under economic constraints [36]. The use of advanced tools like dynamic BPS in particular is crucial for built heritage, as a simplified calculation method is not sufficiently reliable [13, 37]. BPS as a diagnostic tool falls within the Non Destructive Techniques group [1] and is therefore extremely useful when applied to built heritage, as it facilitates the understanding of complex phenomena by studying the relation between the building and the surrounding environment; in addition to supporting energy and environmental improvement interventions, it provides feedback on the evolution of decay phenomena and on the impacts of the intervention on them, and, lastly, it allows to investigate constructive events over the centuries in ways little explored so far (being able to understand how, back in the day, spaces and devices were used to ensure the comfort of occupants, thus providing further elements to the building analysis [25].

The other digital approach that is increasingly being applied to built heritage, because it provides a way to better address heterogeneity and accessibility of conservation processes, is BIM. The acronym BIM is generally used to mean Building Information Model and/or Modeling, referring to both the models created within BIM processes and the process itself; it is defined as the shared digital representation of a built asset that centralizes all the data (geometric and alphanumeric) on it [38, 39]. The BIM approach aims at organizing and managing all the phases of a building intervention, from its design phase up to construction and management. One of the main advantages of a BIM-based approach is the possibility to leverage the power of parametric modeling to increase the quality and flexibility of the model, which can be easily updated over time following the deepening of the analyses; this also reduces redundant operations and raises the accessibility of information that can be queried from the 3D model. The other advantage is the traceability and non-redundancy of the system, which has a positive effect on the velocity of the process (checks and corrections can be performed much more efficiently); lastly, the whole process benefits from this approach thanks to a clear definition of tasks and responsibilities and the enhancement of cooperative work [38]. BIM applied to built heritage is referred to as Heritage BIM (HBIM). HBIM application can also include a strong focus on documentation, thus providing a mean to keep track of all the information pertaining to the building, also if they span several centuries, of how new data was collected, how it was processed and interpreted and how the building changed or evolved after a conservation or energy and environmental improvement process [40].

Both BPS and BIM were developed for new construction and standardized buildings; therefore, transferring them to the built heritage is still an open issue. In both cases, the elaborated geometries involved, the heterogeneous materials and the difficulties in the characterization of structural, constructive and thermophysical properties determine a huge increase in modeling complexity. HBIM research started from mostly geometric-oriented studies [41] and then evolved toward interdisciplinary studies involving a wider array of other disciplines, ranging from historical and architectural analyses to diagnostics [42] and environmental design [25]. A series of increasingly structured references has been made available by sector associations, initially with a geometric focus [43], then also with an interest in the skills of the actors involved [44, 45] and in the BIM process in its entirety [46, 47]. BPS applications to historical buildings are also rising in number, with studies that are now focusing on the thermal representation of the geometry [48] and others that are trying to bridge the gap on other BPS-specific issues, such as the inertial behavior of wall masses, the importance of heat and air moisture transport, and of airflow between zones, infiltrations and the uncertainties related to the thermophysical characterization of the envelope [25, 49]. Moreover, although a simulation-based design process could be managed within a BIM approach, interoperability among the two environments is still lacking and in the development phase [50, 51], with very few cases on historical buildings [25].

4 The Integrated Approach of the Beep Project

The European Neighbourhood Policy launched the ENI CBC Med programme, aiming at bringing together coastal territories of the Mediterranean area to foster fair, equitable and sustainable development on both sides of the EU's external borders. Within ENI CBC Med priorities, the environmental protection and adaptation to climate change and mitigation stressed, in particular, the importance of supporting cost-effective and innovative renovations of public buildings within the specific climatic zone of the Mediterranean area. It is thanks to this programme that the BEEP (BIM for Energy Efficiency in the Public sector) project was able to address the whole process (shown in Fig. 1) of energy and environmental

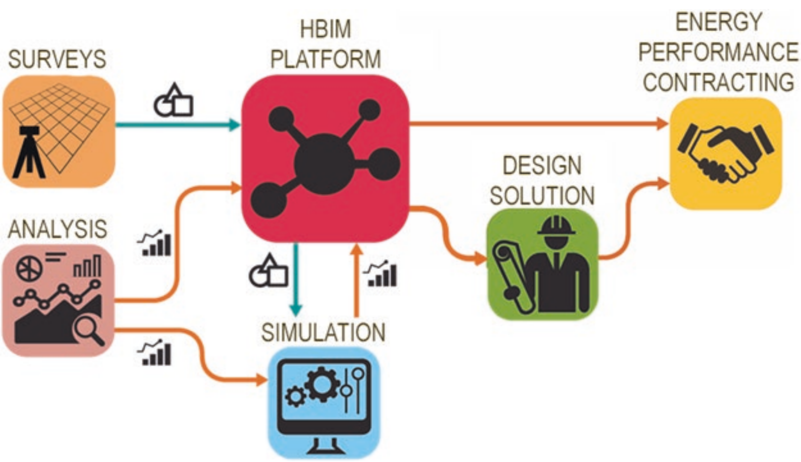

Fig. 1 BEEP process workflow highlighting data and geometry flows of the HBIM-based process

improvement of historical and public buildings and to effectively address climate challenges in the Mediterranean context (and its climatic specificities), thus requiring both a BIM and a dynamic simulation-based approach. The analysis phase was divided into historical and architectural analysis, geometric survey, conservation state analysis and energy and environmental analysis. The data were collected according to specific BIM templates to organize the information for their input in the BIM model and then to support an interoperability process toward the BPS, where the model was first calibrated and then used to foster the development of design interventions. The final outcome was then used as support for innovative financing mechanisms like the Energy Performance Contracting. Nine case studies in 7 different EU and non-EU countries (Italy, Spain, Cyprus, Lebanon, Egypt, Palestine and Jordan) tested the same workflow, that in the end produced a guideline that addresses each step of the process and focuses on its scalability to the professional practice [52].

5 Conclusion

The strong global pressure to evolve our Architectural, Engineering and Construction industry into an energy-efficient and sustainable sector, and the potential that built heritage has in this ambitious switch, is making the development and consolidation of new tools and methods to achieve this goal increasingly important; this is particularly true for historical buildings and their related complexities that generally require a higher skill compared to the rest of the building stock. This process, however, demands a solid theoretical framework to operate and a continuous study of these tools in order to make them scalable to professional practice, especially in the Mediterranean area where the climatic specificities call for a dynamic BPS approach. BEEP project had the merit to address the whole process and develop a guideline capable to guide the stakeholders through it, even in the highly specialized tasks, providing either support for executing the work first-hand or providing an alphabetization and support for outsourcing the tasks. This work will help future professionals and public-owned historical building managers to accelerate the transition toward an energy-efficient historical building stock, thus helping mitigate climate change and protect the buildings from its impacts and from the risk of abandonment.

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References

1. Gigliarelli, E., Calcerano, F., & Cessari, L. (2017). Heritage Bim, numerical simulation and decision support systems: An integrated approach for historical buildings retrofit. *Energy Procedia, 133*, 135–144. https://doi.org/10.1016/j.egypro.2017.09.379
2. WCED. (1987). *Report of the World Commission on Environment and Development (Brundtland commission)*.
3. Houghton, J. T., Jenkins, G. J., & Ephraums, J. J. (1990). *Climate Change The IPCC Scientific Assessment* [Online]. Available: https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_full_report.pdf
4. McG Tegart, W. J., & Sheldon, G. W. (1992). *Climate Change 1992 The supplementary report to the IPCC Impacts Assessment* [Online]. Available: https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_full_report.pdf
5. UN. (1992). *United Nations framework convention on climate change* [Online]. Available: http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf
6. AA. VV. (2012). *Kyoto 1st commitment period (2008–12)*. https://ec.europa.eu/clima/policies/strategies/progress/kyoto_1_en
7. UN. (2015). *Transforming our world: The 2030 Agenda for sustainable development*. United Nations [Online]. Available: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf
8. European Commission. (2015). *The 2030 Agenda for Sustainable Development and the SDGs*. https://ec.europa.eu/environment/sustainable-development/SDGs/index_en.htm
9. Allen, C., Metternicht, G., & Wiedmann, T. (2016). National pathways to the Sustainable Development Goals (SDGs): A comparative review of scenario modelling tools. *Environmental Science & Policy, 66*, 199–207. https://doi.org/10.1016/j.envsci.2016.09.008
10. Laine, A., Davies, J., Buchanan, K., Warren, K., & Turtinen, J. (2019). *Heritage Research Matters. Case studies of research impact contributing to sustainable development* [Online]. Available: http://jpi-ch.eu/wp-content/uploads/Heritage-Research-Matters.pdf
11. AA. VV. (2013). *The Hangzhou Declaration. Placing culture at the heart of sustainable development policies*.
12. H2020 Expert Group on Cultural Heritage. (2015). *Getting cultural heritage to work for Europe - Report of the Horizon 2020 Expert Group on Cultural Heritage*. Directorate-General for Research and Innovation.
13. Y. Directorate-General for Education. (2022). *Strengthening cultural heritage resilience for climate change: Where the European Green Deal meets cultural heritage*. LU: Publications Office of the European Union [Online]. Available: https://data.europa.eu/doi/10.2766/44688. Accessed 09 September 2022.
14. Potts, A. (2021). *European cultural heritage green paper*. Europa Nostra.
15. European Parliament. (2020). *A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives*. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/fs_20_40
16. EC. (2021). *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast)*.
17. Carbonara, G. (2015). Energy efficiency as a protection tool. *Energy and Buildings, 95*, 9–12. https://doi.org/10.1016/j.enbuild.2014.12.052
18. Bonelli, R. (1959). *Architettura e Restauro*. Pozza.
19. VV. AA. (1932). *Athens Charter*.
20. Morin, E. (1990). *Introduction à la pensée complexe*.
21. Grassi, L. (1981). Problemi metodologici in relazione alla teoria del restauro. *Il Restauro Delle Costr. Muratura Probl. Metodol. E Tec. Consolidamento*, 9–11.
22. Pane, R. (1987). *Attualità e dialettica nel restauro*, edited by Mauro Civita. Chieti.
23. Carbonara, G. (1997). *Avvicinamento al Restauro. Teoria, storia, monumenti*. Napoli.

24. Croci, G. (2000). General methodology for the structural restoration of historic buildings: The cases of the Tower of Pisa and the Basilica of Assisi. *Journal of Cultural Heritage, 1*(1), 7–18. https://doi.org/10.1016/S1296-2074(99)00119-3
25. Gigliarelli, E., Calcerano, F., D'Uffizi, F., Di Biccari, C., Mangialardi, G., & Campari, M. (2019). *From Heritage BIM to BPS, a computational design-based interoperability approach*, presented at the BS2019, Rome.
26. EP. (2010). *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*.
27. (EURAC research) Troi, A., & Z. (Passive H. I. Bastian). (2014). *Energy efficiency solutions for historic buildings. A handbook*. Birkhäuser. https://doi.org/10.1515/9783038216506
28. Eriksson, P., Hermann, C., Hrabovszky-Horváth, S., & Rodwell, D. (2014). EFFESUS methodology for assessing the impacts of energy-related retrofit measures on heritage significance. *The Historic Environment: Policy & Practice, 5*(2), 132–149. https://doi.org/10.1179/1756750514Z.00000000054
29. Leissner, J., et al. (2015). Climate for Culture: Assessing the impact of climate change on the future indoor climate in historic buildings using simulations. *Heritage Science, 3*(1). https://doi.org/10.1186/s40494-015-0067-9
30. Webb, A. L. (2017). Energy retrofits in historic and traditional buildings: A review of problems and methods. *Renewable and Sustainable Energy Reviews, 77*, 748–759. https://doi.org/10.1016/j.rser.2017.01.145
31. V. AA. Energy Heritage. (2008). *A guide to improving energy efficiency in traditional and historic homes*. Changework resources for life [Online]. Available: http://www.changeworks.org.uk/resources/energy-heritage-a-guide-to-improving-energy-efficiency-in-traditional-and-historic-homes
32. MIBACT. (2015). *Linee di indirizzo per il miglioramento dell'efficienza energetica nel patrimonio culturale. Architettura, centri e nuclei storici ed urbani*. Ministero dei beni e delle attività culturali e del turismo Direzione generale Belle Arti e Paesaggio [Online]. Available: http://www.beap.beniculturali.it/opencms/multimedia/BASAE/documents/2015/10/27/1445954374955_Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf
33. Augenbroe, G. (Aug. 2002). Trends in building simulation. *Building and Environment, 37*(8–9), 891–902. https://doi.org/10.1016/S0360-1323(02)00041-0
34. Hensen, J. L. M. (2004). Towards more effective use of building performance simulation in design. In J. P. Leeuwen & H. J. P. Van Timmermans (Eds.), *7th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, July 2–5*. Eindhoven University of Technology.
35. Hong, T., Chou, S. K., & Bong, T. Y. (2000). Building simulation: an overview of developments and information sources. *Building and Environment, 35*(4), 347–361. https://doi.org/10.1016/S0360-1323(99)00023-2
36. Clarke, J. A., & Hensen, J. L. M. (2015). Integrated building performance simulation: Progress, prospects and requirements. *Building and Environment, 91*, 294–306. https://doi.org/10.1016/j.buildenv.2015.04.002
37. Calzolari, M. (2016). *PRESTAZIONE ENERGETICA DELLE ARCHITETTURE STORICHE: SFIDE E SOLUZIONI Analisi dei metodi di calcolo per la definizione del comportamento energetico*. Franco Angeli.
38. ISO 19650. (2018). *ISO 19650:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling —*.
39. National BIM. (2007). *Standard buildingSMARTalliance, National Building Information Modelling standard*. National Institute of Building Sciences.
40. Martinelli, L., Calcerano, F., & Gigliarelli, E. (May 2022). Methodology for an HBIM workflow focused on the representation of construction systems of built heritage. *Journal of Cultural Heritage, 55*, 277–289. https://doi.org/10.1016/j.culher.2022.03.016

41. Murphy, M. (2012). *Historic Building Information Modelling (HBIM). For recording and documenting classical architecture in Dublin from 1700 to 1830*, Ph.D. Dissertation. Department of Chivil, Structural & Environmental Engineering, Trinity College Dublin.
42. Bruno, S. (2018). *The implementation of automatic diagnostics and monitoring towards Diagnosis-Aided Historic Building Information Modelling and Management*, Ph.D. Thesis. Politecnico di Bari - DICATECh Department of Civil, Environmental, Land, Building Engineering and Chemistry.
43. Maxwell, I. (2014). *Integrating digital technologies in support of Historic Building Information modelling: BIM4Conservation (HBIM)*. COTAC. [Online]. Available: http://www.cotac.global/resources/COTAC-HBIM-Report-Final-A-21-April-2014-2-small.pdf
44. Maxwell, I. (2016). *COTAC BIM4C Integrating HBIM Framework Report Part 1: Conservation parameters*. COTAC [Online]. Available: http://www.cotac.global/resources/HBIM-Framework-Part-1-February-2016.pdf
45. Maxwell, I. (2016). *COTAC BIM4C integrating HBIM Framework Report Part 2: Conservation influences*. COTAC [Online]. Available: http://www.cotac.global/resources/HBIM-Framework-Part-2-February-2016.pdf
46. Antonopoulou, S., & Bryan, P. (2017). *BIM for heritage - Developing a historic building information model*. Historic England.
47. Historic England. (2019). *BIM for heritage: Developing the asset information model*. Historic England.
48. Akkurt, G. G., et al. (Feb. 2020). Dynamic thermal and hygrometric simulation of historical buildings: Critical factors and possible solutions. *Renewable and Sustainable Energy Reviews, 118*, 109509. https://doi.org/10.1016/j.rser.2019.109509
49. Widström, T., Bjrk, F., Gudmundsson, K., & Arfvidsson, J. (2019). *Simulation of historic buildings for enhancement of preservation and energy performance - issues and methods*. KTH Royal Institute of Technology.
50. Pinheiro, S., et al. (Jun. 2018). MVD based information exchange between BIM and building energy performance simulation. *Automation in Construction, 90*, 91–103. https://doi.org/10.1016/j.autcon.2018.02.009
51. Andriamamonjy, A., Saelens, D., & Klein, R. (2019). A combined scientometric and conventional literature review to grasp the entire BIM knowledge and its integration with energy simulation. *Journal of Building Engineering, 22*, 513–527. https://doi.org/10.1016/j.jobe.2018.12.021
52. Calcerano, F., Thravalou S., Martinelli L., Alexandrou K., Artopoulos G., & Gigliarelli E. (2023). *Energy and Environmental Improvement of Built Heritage: HBIM Simulation-Based Approach Applied to Nine Mediterranean Case-Studies*. Building Research & Information, May. https://doi.org/10.1080/09613218.2023.2204417

Investigation on the Chance of Applying Bioclimatic Solutions for Ancient Architectures' Regeneration

Dora Francese and Luca Buoninconti

1 Introduction

Technology, i.e. the base concept of transformation of land, has become a difficult word to mention, for either it acquires the significance of hard systems for aggression to the world, or means the information processes nowadays core of the so-called digital transition.

Digital technologies applied to the construction sector [4] regard both soft and hard elements, so including the materials, the components, the products, the processes, …, and last but not least also the digital tools and systems, any time they apply to one or more of the building process stages.

This preliminary and obvious declaration is meant to introduce a new concept which non directly descends from the technological use of our Planet, but actually interacts with any techniques and so with the investigation and methodology of the processes, also in the architectural field.

This concept, from a number of parts already established as updated and adapt to the historical moment of human civilization, is the idea that we live in the age of space.

In 1967 Foucault reflected on the idea that the great obsession of the nineteenth century had been the history, therefore the time, and the process of transforming along some various proceeding steps different in terms of quality, fashion, progress, inventions, innovations, and maturity.

The twenty-first century "… can instead be considered as the age of space: a period of synchronism, of juxtaposition, of the close and far aspects, of the side by side systems, or the dispersed items … today it is crucial to understand the

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relationship between spaces and flows, between spaces without space, times without time" [7].

The metaphor, employed by the well-known psychologist and scholar Lingiardi for describing the new virtual life joined with the concrete procedure of human existence, can actually be interpreted as a goal to achieve during any action for earth transformation, which therefore can take into account the real and the virtual in the just relationship and size, in order to consider the earth as something to be protected and safeguarded rather than to be exploited and abused.

In the last analysis, the sustainable employment of the digital systems can actually be achieved where the aforesaid concept is considered as a method and means rather than as a goal, a desire.

The question of space as dominant in our age is determinant "… not only for the disciplines that turn the space and the places into their election matter (architecture, geography, environmental sciences, ecology…) but also for the psychoanalysis" [7].

In the present historical moment, digital space has become increasingly diffused and significant for human activities, and architecture is not an exception: beyond the boundaries of sustainability, digital reality can substitute concrete and brutal construction; even in the historical zones of urban and rural character, one of the solutions for achieving respectful, non-aggressive and temporary goals can be indeed identified with digital and reversible technologies.

2 Case Study, Orta Di Atella, Territorial Emergences

The case study has been selected according to the need of developing strategies for the recovery of rural farmhouses, which are very collective in the Campania Region's historic heritage. The portion of land, found suitable for the application of the aforesaid strategic design procedure with parametric tools, is located in the Caserta district, anciently known as Terra di Lavoro (work ground), due to its marked agricultural destination, mainly in the period preceding the union of Italy (AA.VV. 1986).

The identified place is the small city of Orta di Atella, at the south border of the metropolitan city of Naples, today populated by almost 30,000 inhabitants[1] but in the past reaching only a ten times smaller people density[2]; the present urban built-up area, expanding from San Cipriano d'Aversa toward the south-east, through Aversa, Orta, Grumo Nevano, Afragola and Casoria till reaching the northern boundary of the Regional main city (Naples), had been once occupied by the fertile land of Campania Felix. The regional valley was for this reason scarcely built: exclusively ancient farmhouses were there standing (villæ rusticæ) for keeping the fields, and

[1] See: https://www.istat.it/it/dati-analisi-e-prodotti/contenuti-interattivi/popolazione-residente (visited on 2.3.2022).

[2] See: Ministero di Industria, Agricoltura e Commercio [8].

Fig. 1 Satellite picture of the urban agglomeration of Succivo, Orta di Atella, Sant'Arpino and Frattaminore

Orta itself was not an exception, as indeed demonstrated by its toponym, directly coming from the ancient Latin word hortus, the term usually attributed to a ground destined to cultivation, in contrast with the locution *sub se civus ager*,[3] which, conversely, names a non-centurial land portion, and thus left wild [5]. At the present state, the edification invades the rural zone, both due to the exponential demographic pressure, which had invested the outskirt which gravitates around the metropolitan area of Naples and to the growth of productive activities in the secondary and tertiary sectors, by means of the appearance of industrial structures, now characterizing the landscape (Fig. 1).

The area without construction appears now as an isolated place surrounded by built structures, and the various villages are no longer distinguished from each other's, for they are fused into a unique urban system. In the absence of municipal borders, it becomes impossible, for example, to identify Orta di Atella from Succivo or Frattaminore. For its peculiar articulation, expanding from an urban built-up area toward the North, the municipal territory of Orta has been only partially occupied by built elements, i.e. for a covered surface equal to 35% of the whole extension: in fact, in the northern area-wide zones are still to be found which are scarcely edified and for a sensible portion destined to agriculture. The building selected for the parametric requalification is a nineteenth-century fabric in a rural zone far from residential areas: this occurrence can help to process a simplified digital model, as a result of the fact that physical phenomena to be simulated are not affected by activities'

[3] This Latin expression is at the origin of the toponym *Succivo*, which is the name of the town near Orta.

Fig. 2 Photogrammetry of Orta di Atella

presence, both human and built (housing, infrastructures, industrial areas), in the surrounding. So efficiency and adherence to the actual model, on which the simulation process is based, are verified, thanks indeed to the reduced amount of running variables (Fig. 2).

3 Morphological and Technological Survey

In the northern part of the Municipality, then, before reaching a big Shopping Mall (Centro Commerciale Campania) and the industrial area of Marcianise, in the place called Ponte Rotto, a portion of land still flat, agricultural and almost lacking construction can be found, which represents the eventual state of the landscape before the demographic outbreak.

Here indeed the Minutolo farmhouse raises a rural construction, absolutely isolated from the urban context (Fig. 3), and appears interesting for this research's goals, due to its environmental conditions, which are very simple to model and calculate, due to the already mentioned fact that physical phenomena to be simulated are not affected by other buildings' or human activities' presence.

Given the aforesaid land use, climatic conditions observed in the place – identified as Csa according to the Köppen's classification [9], corresponding to a warm Mediterranean climate – are characterized by lower temperatures than in the inhabited zone, where slightly moderate urban heat island [12] can be observed, and following higher humidity values, due to the saturated vapour pressure's drop [2].

The site's ventilation can be assessed by employing the data available in the military meteorological station in Grazzanise, which is distant about twenty kilometers,

Fig. 3 Satellite view of Minutolo farmhouse and the agricultural context

where the prevailing winds blow from Northeast in winter and South West in summer, from midday till the evening. Due to the peculiar flat morphology of the ground, the wind direction is very unlikely to undergo relevant variations, and hits directly the farmhouse, also because no screening elements, such as trees or plants, can actually appear in between.

The farmhouse is shown as a ruin (Fig. 4) and presents a unitary building at simple block [1], to which probably a protruding element was once added – maybe a porch or a canopy under a balcony supported by a lower arch – on the north façade. The main fabric body, dated 1868, as easily derived from a written inscription engraved in an angular stone at the top, has a rectangular shape, sized 8.40 by 7.12 metres, arising for two stores to which an attic is added, opening under the double pitched roof, today collapsed on the south side, with a maximum height which reaches almost ten meters. As it happens for unfinished works, the dimensions are susceptible to a degree of uncertainty which in some cases can touch even ten centimeters. An internal staircase, shaped like an L, allowed to reach the upper level directly from the ground floor (Fig. 5).

The processed geometrical survey has permitted to develop a tridimensional model thanks to which the solar investigation can be developed, in order to study the zones, hit by the sun's rays and those in shadow, both in summer and in winter. With the aid of the polar solar diagram, it is possible to trace the obstructions around the building, and later on to determine the shadings carried by the building itself in defined day hours; in this case, the selected times were 9.00, noon and 3.00 PM of December the 23rd and June the 21st. The result shown in Fig. 6 allows us to characterize the zone at better thermal comfort in winter and summer, according to solar irradiation.

Fig. 4 View of the farmhouse from the north side

As far as the material viewpoint is concerned, the absence of coating layers (plaster, paintings, suspended ceilings) shows directly the unfinished works and facilitates an extremely detailed camera survey. The level of knowledge can be pushed until assessing a deep clear knowledge of the cracking frame which hit the supporting walls, so allowing also to hypotize eventual completion works for structural consolidation.[4]

Vertical parts are built in a vernacular technology called "a sacco" (sack), with two external layers in yellow Neapolitan tufa stone and a filling with graves at various granulometry; a tapering between the ground and the first floor leads to a decreasing thickness of the wall from 86 till 58 cm; vertical elements sustain two timber floors with circular beams – maybe in chestnut or oak wood – linked each others with irregular joists still partially visible. The roof, with the shape of a hut, is processed as a tilted floor covered with roof tiles still clear in the pitched north side, while fully disappearing in the south zone. Interesting is the opening system, made up of both arched and flat: the round arches are in the large windows on the east front and on the lateral small windows, and in the frames on the south and north sides; low arches are well visible in the balcony support (now almost completely disappeared) and in the doors for the passages at North and West. Even though the developed model for this study does not preview a material survey, nevertheless the precision of this analysis could allow to implement of the structures in a suitable calculation software and to process also a static and dynamic simulation for the

[4] Part of the research has been developed as a degree thesis in Architecture. (Students: Orizzonte C, Chianese M; Tutors: proff. Francese D, De Martino G., Siani. R, Buoninconti L.).

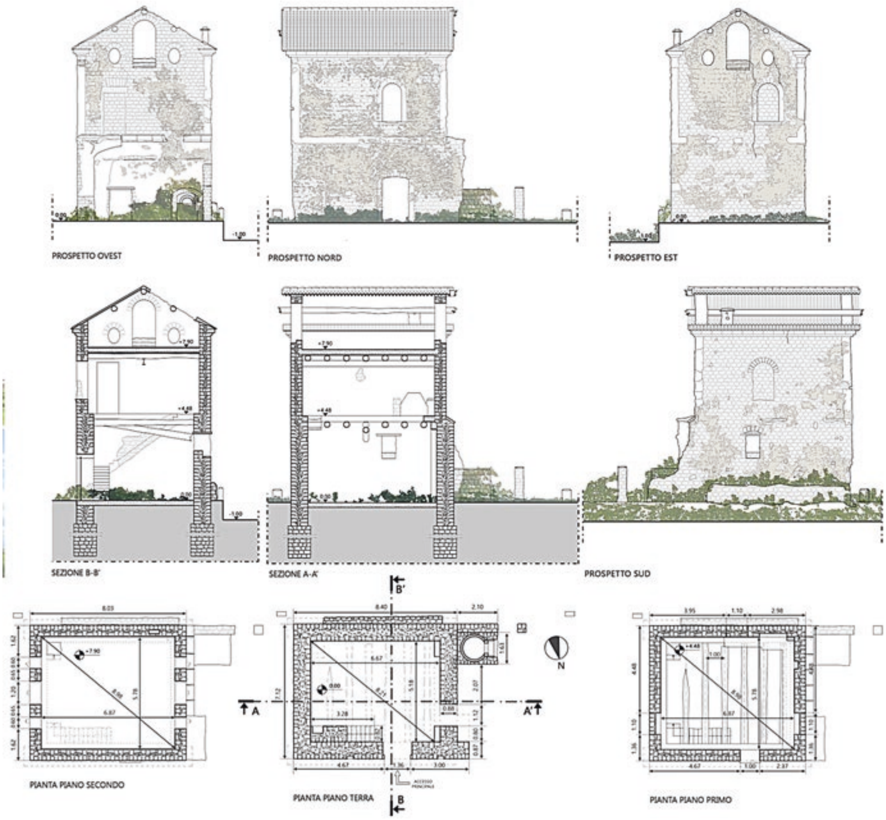

Fig. 5 Geometric survey

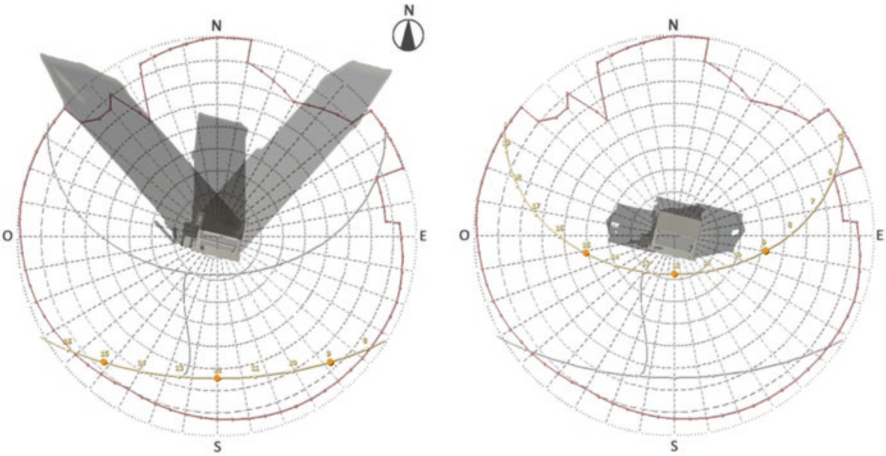

Fig. 6 Solar analysis performed on the winter solstice and, on the right, summer solstice at 9:00, 12:00 and 15:00

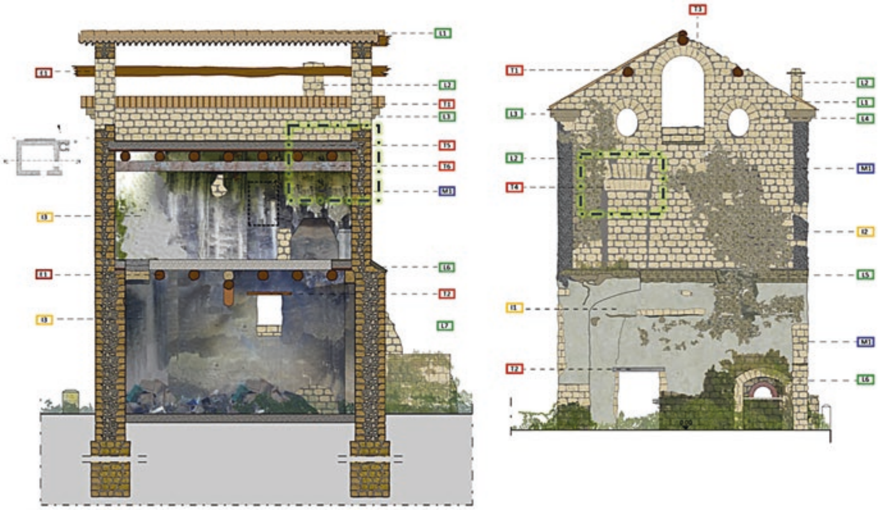

Fig. 7 The material survey on section AA 'and on the west elevation

behavior of foundation and elevation structures, by means of increasing the knowledge level of the work, also from the mechanical resistance point of view (Fig. 7).

4 Parametric Screen System

From the processed analysis, both climatic and formal-material ones, a critical point emerged, i.e. that the building is highly and completely exposed to both sun and wind, so defining the need of protecting the indoor rooms from the first in summer and from the last in winter. In order to alternate the solution according to the temporary problem, a number of light shading systems have been proposed, which will also be disassembled, able to adapt their configuration according to the seasonal changes. The idea of adding a new skin to the building and that of rejecting the chance of directly operating on the physical characteristics of the existing closures are due to the consideration according to which the wall thermal resistance is already enough for guaranteeing law requirements. The use of dry joints and light elements, fundamental for completing easily the disassembling parts, are conventional requirements also for environmental sustainability: these requirements count, among others, the use of materials at a high level of naturality and at reduced Ecological Footprint [6]. For these reasons, another operating choice was oriented towards the use of vegetable materials, for they are usually provided with a low environmental load [14] and with an optimal relationship between specific weight and mechanical resistance.[5]

[5] See also: https://www00.unibg.it/dati/corsi/60044/69775-Legno%20-%20proprietà%20fisico-meccaniche.pdf

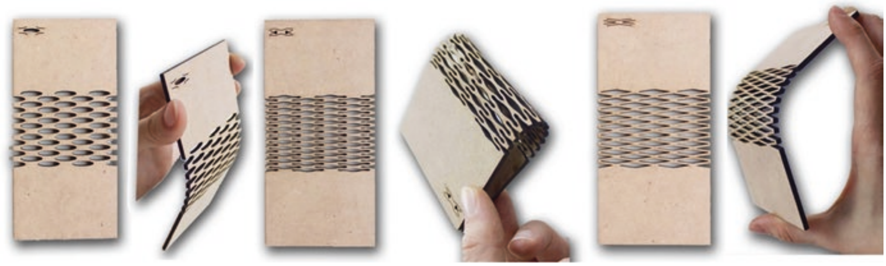

Fig. 8 Latex oval, elliptical and rhomboid hinge, in hemp panels

The pine tree timber, and the fir in particular, if coming from controlled-growth forests, owns both the sustainability performances and the structural efficiency,[6] needed for the proposed scope [10]. The option then has been processed towards a double-skin system, in which the supporting frame could be completed with fir wood, could be dry assembled, and to which the shading screens with easily demountable panels should be joined. Therefore, the chance of employing rigid panels in hemp has been considered. The technology previews the creation of a reticular linkage, with overlapping cuts aimed at increasing the flexibility and partial modeling (Fig. 8).

From the formal point of view, the chance of employing various panels' geometry allows more expressive solutions, but also efficient from the technical as well as functional aspects. Provided the high variety of configurations, and the different involvement of the number of running factors, a peculiar algorithm has been processed, suitable for arranging as the system the different design parameters included in the definition of the element, such as:

- The initial size of the hemp panel.
- The curvature to be impressed to the various panel systems (Fig. 9).
- The dimensions of the shafts arranging the timber frame, according to the loads to be supported.
- The amount of shading surface projected by the panels over the facades on which the double skin should be applied.
- The location of the cuts for the creation of net linkages, which, according to the established curvature, generate parts with major or minor permeability to light and wind; (they will be strategically located in fact where there are existing openings on the facades).

The algorithm has been then parametrized according to the distance between two piers of the frame, which can be modified so as to obtain in real time the remaining values (length and curvature of the panel, shading surface, air and light transfer).

[6] A class C24 fir, according to the UNI EN 11035-2: 2010 standard, has a compressive strength perpendicular to the grain of 21.0 MPa and an average specific weight of 4.41 kN / m^3: its mechanical efficiency, therefore, is 4761 m, an average value higher than that of steel (between 3000 and 4000 meters).

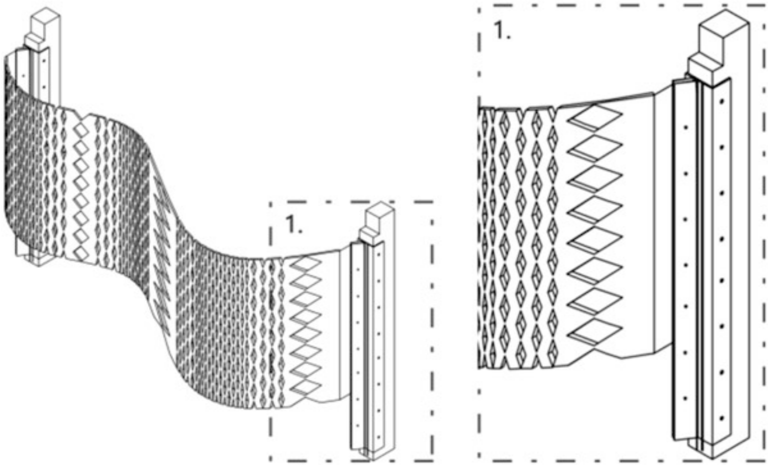

Fig. 9 Example of panel curvature, and connection to the fir frame

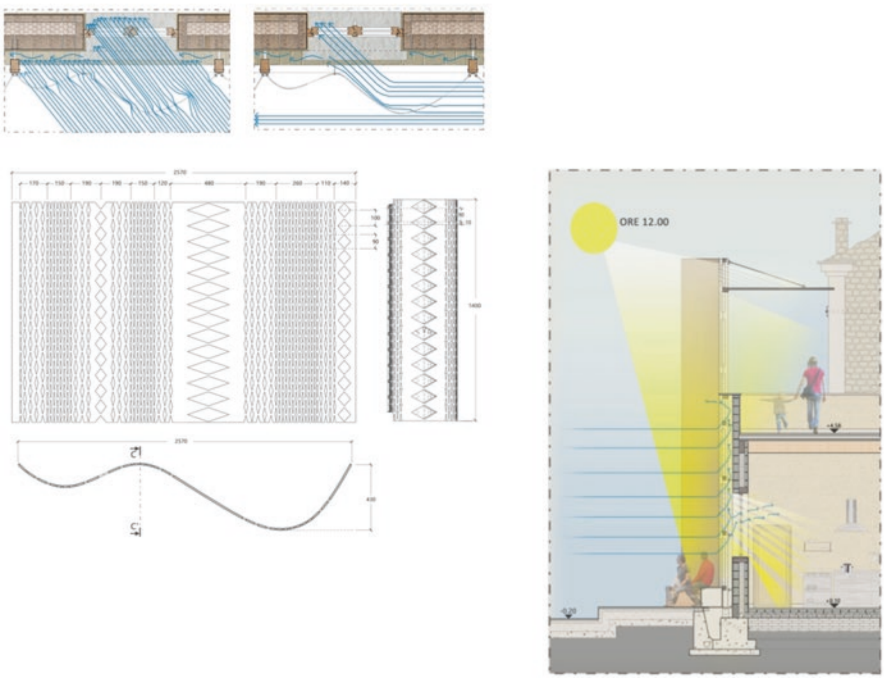

Fig. 10 Study of the air and light permeability of the solution for the panel

The software employed in this research is a calculation sheet, although it can be possible to make use of peculiar languages combined with CA and BIM procedures, like Dynamo for Autodesk, Revit or Grasshopper for Rhyno [13], which are simpler to be used for they directly return a tri-dimensional model.

Thanks to this digital tool, a solution has been identified with triple curvature, which happens to be very interesting for the values regarding lighting, ventilation and structure dimension (Fig. 10). However, it is fundamental to observe that the parameterized algorithm has not been created with the aim of obtaining a peculiar optimized solution, according to a specific reference criterion: instead, it has been used for quickly testing a number of different design solutions, while leaving to the designer the task of selecting what is formally, technologically and functionally more appropriate. Nevertheless the chance of including in the calculation also a multicriteria assessment system can be processed, so as to allow the tool to find the optimized solution for the specific problem.

5 Conclusion

The proposed research's approach considers digital procedures as tools for knowledge, design, and safeguard of various elements of the cultural anthropic heritage, because innovation is essential in the technology as part of the human creative actions aimed at improving the life on earth.

These brief notes are meant to align digital studies with the power of imagination, which is not only directed towards a new structure and shape of the territory but can also be employed for respecting and conserving the beauty of the existing natural as well as a cultural landscape. We can remind Borghes who, in one of his books, tells about a man who proposes to "draw the world", by collecting images of mountains, islands, bays, houses, asters and vessels [7]: therefore, the imagination, which is part of the creative aspects of the design procedure, can easily and deeply been exploited also for re-establishing balance in the landscape, by means of the memory of the places. "The places talk (in fact) by means of the memories … through our brains, our hearts, our bonds." [7].

The design has the duty of including the memory of the underground, spiritual, physical, morphological and social landscape of the surroundings: the parametric design is demonstrated to be suitable for this task, due to the fact that it is in unison with an innovative-scientific process, and an operation which allows the customization, thus the presence of subjective values as well as local, as residual elements of the place and of the past forgotten times.

In fact, the 'informed prototype' of architecture by parametrical solutions doesn't generate strictly established shapes but can vary so taking into account the memory of cultural landscape besides the natural environment. The latest can be included in the parametric system, by means of biomimetic solutions [3].

These solutions, 'optimized' according to a referenced natural phenomenon, as in this case apparent solar path, allows to harmonize beauty and sustainability [11].

References

1. Barbieri, G., & Gambi, L. (1982). *La casa rurale in Italia*. L. S. Olschki.
2. Bellia, L., Mazzei, P., Minichiello, F., & Palma, D. (2006). *Aria umida. Climatizzazione ed involucro edilizio*. Liguori editore.
3. Benyos, J. M. (2009). *Biomimicry*. HarperCollins.
4. Ciribini, G. (1995). *Tecnologia e Progetto: argomenti di cultura tecnologia della progettazione*. Celid.
5. Fodi, M. (1964). *La casa rurale nella Campania*. L. S. Olschki.
6. Giachetta, A. (2010). *Il progetto ecologico oggi: visioni contrapposte*. Alinea.
7. Lingiardi, V. (2017). *Mindscapes. Psiche nel paesaggio*. Raffaello Cortina ed.
8. Ministero di Industria, Agricoltura e Commercio. (1861). *Censimento del Regno d'Italia*, p. 99. Stamperia reale.
9. Peel, M. C., Finalyson, B. L., & McMahon, T. A. (2007). *Updated World Map of the Köppen-Geiger Climate Classification*. Copernicus Publications.
10. Piazza, M., Modena, R., & Tomasi, M. (2005). *Strutture in legno. Materiale, calcolo e progetto secondo le nuove normative europee*. Hoepli.
11. Pontikis, K., & Rofe, Y. (2016). *In Pursuit of a Living Architecture: Continuing Christopher Alexander's Quest for a Humane and Sustainable Building Culture*. Common Ground Publishing.
12. Stewart, I. D., & Mills, G. (2021). *The urban heat Island*. Elsevier.
13. Tedeschi, A. (2006). *Architettura parametrica. Introduzione a Grasshopper*. Le Penseur edizioni.
14. Valcovich, E., Fernetti, V., & Stival, C. A. (2011). *Un approccio ecosostenibilie alla progettazione edilizia*. Alinea.

Satellite Imagery and AI Techniques in Geospatial Analysis to Enhance Environmental Sustainability

Application on Urban Green Space in the City of Rabat Morocco

Mariame Chahbi

1 Introduction

The world today is undergoing a rapid transition. The abundance of data and digital transformation is setting everyday life activities with artificial intelligence in order to improve livability, enhance the quality of life, increase economic opportunities and hence build strong and integrated communities.

Computer science is blooming day by day, scientists have been striving to make machines able to see, analyze, and understand the world same as the human brain does. Using Data, machine learning can find important correlations between data in a short time having the ability to investigate and find solutions for difficult and complex issues which surpass human understanding capability [1]. Today, data becomes more and more available. The area of urban data collection is highly demanded for the most part for machine learning applications such as deep learning, pattern recognition, visual assistant, text translation etc. One of the strongest tools that provide a great amount of urban data is satellite imagery which can provide an error-free and accurate representation of the real world coming up with detailed data using high-resolution captures.

Owing to the advantage of new technologies, the quantity and quality of green space can be tracked using high-resolution satellite imagery. Computational tools such as deep learning techniques included with Qgis software using computational tools are being used for this analysis to give an overall estimation of urban green space quantity and quality.

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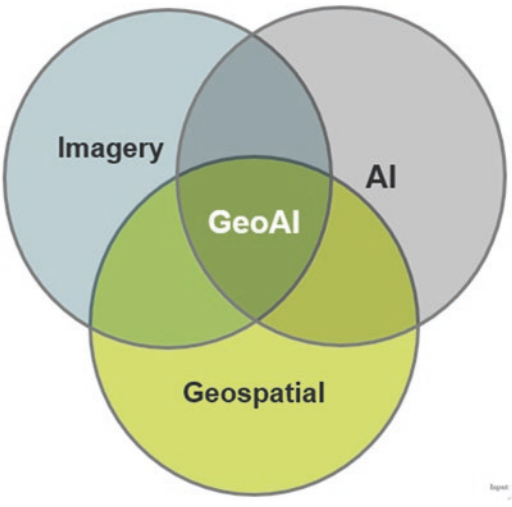
2 Geospatial Data Combined with AI

Geospatial data are spreading fast and are applied in several fields such as smart cities, urban mobility and transportation, public security, business and economic opportunities, health services, resilience to natural disasters etc. by controlling these issues, the main aim is to enhance the quality of life and livability in urban areas. In urban planning, the computational models have been used with co-occurrence with the geospatial analysis in several means such as classification, clustering, and prediction [2]. GeoAI, (Fig. 1) a cutting-edge field in geospatial technology, leverages the power of artificial intelligence (AI) to analyze and extract valuable insights from imagery and geospatial data. By combining these two domains, GeoAI revolutionizes the way we interpret and understand the ground's surface.

In Urban analysis, classification can be used in several ways, to detect land-use patterns [3], extract green areas from satellite images using machine learning techniques, and can be easily used to carry out any spatial analysis. On the other side, clustering techniques are generally used to initiate model indicators of urban forms. As for prediction, a spatial regression algorithm can be used to model and predict future urban development. Combined with Artificial Intelligence, Geographic Information System (GIS) data analyzes urban growth and the direction of expansion. When properly applied, it can come across new areas for future urban extension. The fusion of geospatial data and AI not only enhances our ability to understand the Earth's surface but also opens up new opportunities for sustainable development, resource management, and informed decision-making. The technology continues to evolve, empowering researchers, policymakers, and industries to tackle complex challenges and unlock the full potential of geospatial information.

AI refers to computational methods that can perform tasks that normally require human intelligence, such as reasoning, learning and foresight that enable it to

Fig. 1 GeoAI, integrating AI with GIS



function appropriately in its environment. It englobes Machine learning, which is a subfield in AI that relies on statistical methods or numerical optimization techniques to derive models from data (Fig. 3).

Deep Learning is a special type of machine learning where artificial neural networks ANN, and algorithms inspired by the human brain, learn the patterns and prediction rules from large amounts of data (Fig. 2). Data matters, without the data models, cannot be trained nor calibrated [1, 5, 6]. Data collection is crucial. The Network training process cannot be done without sufficient data. Basic knowledge in coding and computer science fundamentals is required for this task, Once the model is trained, the margin of error is calculated. If the calculated margin of error is deemed unacceptable, the network needs to be retrained and recalibrated repeatedly until achieving accurate results with an acceptable error percentage. Once this threshold is reached, the model can be validated. The validated model's target output can then be utilized for design and decision making purposes.

3 Fields of Application of GeoAI

The combination of Artificial Intelligence methods with Geographic Information System (GIS) and geospatial is called GeoAI. It is a new form of machine learning based on a geographic component combining innovations in spatial science, AI/ML methods (e.g., deep learning), and high-performance computing to extract knowledge from spatial big data, Alastal A, et al. [7]. The integration of AI with geospatial data enables a range of applications (Fig. 4). For example, GeoAI can help in urban planning by analyzing satellite imagery to identify land use patterns, assess

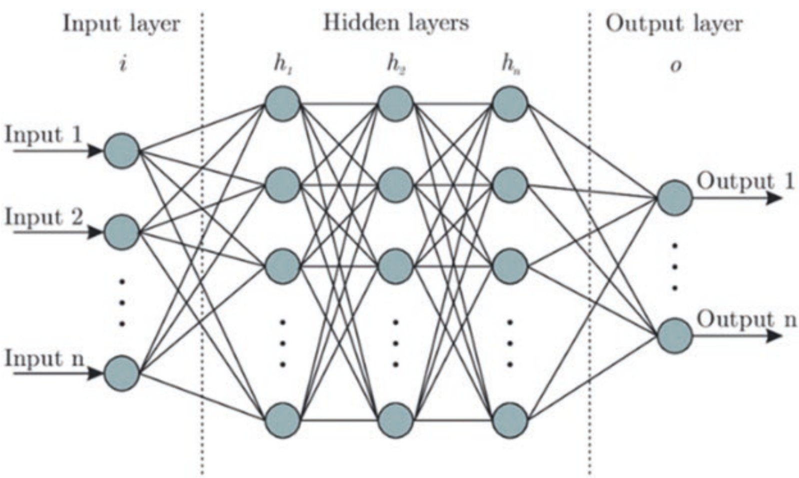


Fig. 2 Simplified deep learning model [4]

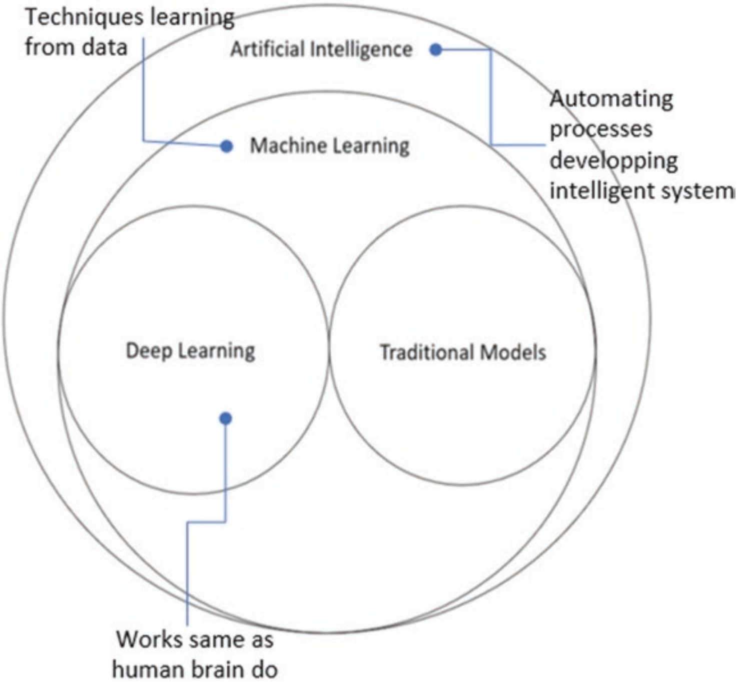


Fig. 3 The position of deep learning vs machine learning (ML) and artificial intelligence (AI)

Fig. 4 Fields of application of GeoAI. (Image created based on Alastal A, et al. [7])

infrastructure needs, and predict population growth. It can also support environmental monitoring by detecting deforestation, tracking changes in ecosystems, and assessing the health of vegetation which is the main focus of this study.

4 Study Area

In this research, the city of Rabat has been selected as a field of study. Rabat, the capital of Morocco is located on the edge of the Atlantic Ocean in the northwest of Morocco. covering an area of 118.5 km27 from which around 230 hectares are deployed for green space (Fig. 5). It contains around a population of 645 500 inhabitants without including its suburbs. From an administrative view, the urban municipality of Rabat is divided into five districts (Fig. 6):

1. District of Hassan
2. District of Agdal-Ryad
3. District of el-Youssoufia
4. District of Yacoub el-Mansour
5. District of Souissi

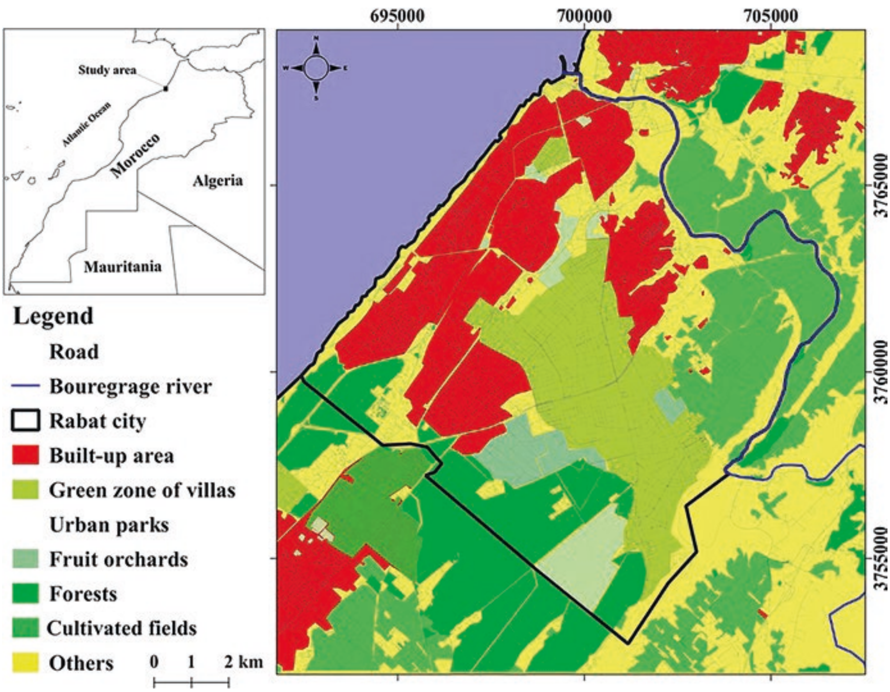


Fig. 5 Urban green space and delimitation of the city of Rabat [8]

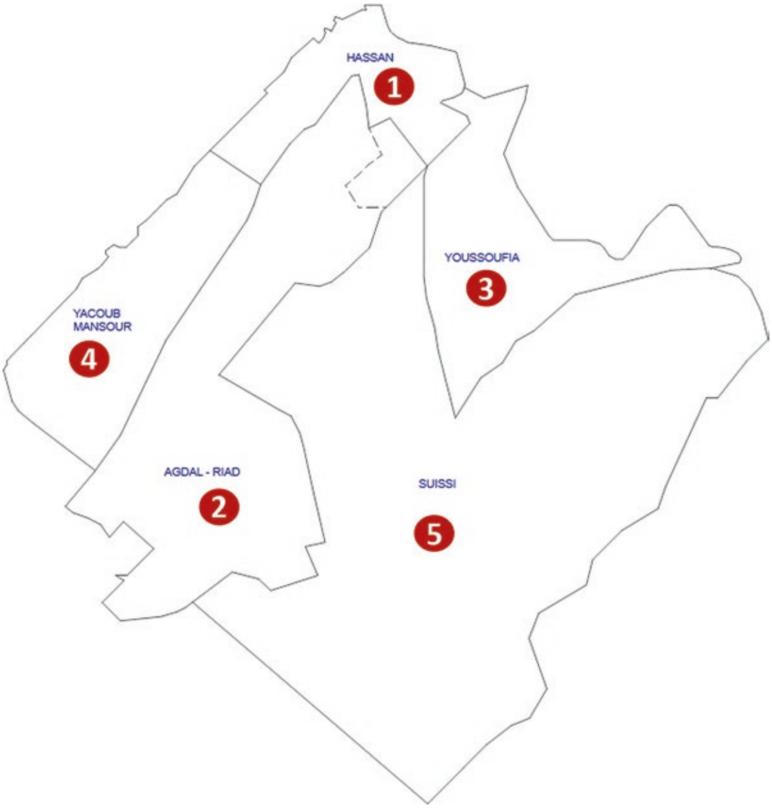


Fig. 6 Delimitation of the five administrative districts of Rabat. (vector map generated by the Author)

5 Material and Methods

In this study, the material used is mainly based on the Satellite imagery of the city of Rabat issued from Sentinel-2 satellite by the United States Geological Survey earth explorer (USGS) launched in 2015, and the administrative map of Rabat showing the five different administrative communes of Rabat to measure and assess the green space quality of the different districts. From previous studies [9–11] there is a list of remote sensing indices available that has been constructed from the information available at the index database (IDB) specifically for Sentinel-2 satellite related to green space quality assessment. Among this list, three vegetation indices have been selected (Table 1) to be applied in the perimeter of the city of Rabat to assess its environmental quality based on green space quality and quantity measurement.

Table. 1 The vegetation-related indicators used in this study to assess the urban green space quality in the city of Rabat

NDVI: Normalized Difference Vegetation Index1 (NDVI) [11] Formula: (NIR−RED)/(NIR+RED)
EVI: Enhanced Vegetation Index (EVI) [12] Formula: EVI = 2.5*(NIR − RED) / (NIR + 6*RED − 7.5*BLUE + 1)
VARI: Visible Atmospherically Resistant Index (VARI) [13] Formula: VARI = (Green − Red) / (Green + Red – Blue)

There are different types of GIS software applications that can help ensure geographical spatial analysis, which can produce, control, analyze and represent data on the map. Here is a list of the most important GIS software available and accessible: Qgis, ArcGis, GlobalMapper, open jump SagaGis (System for Automated Geoscientific Analyses) and GrassGis (Geographic Resources Analysis Support System), Alastal A, et al. [7]. For this study, Qgis is used, as open-source software and is accessible for all.

Remote sensing data is a perfect source to extract vegetal indicators as satellite imagery can provide a big amount of spatial data that can be examined, and processed to provide useful outputs helping to understand several vegetation indices. “The red-edge bands of Sentinel-2 allow for a greater diversity of spectral Vegetation Indices (VIs) to be calculated and used for vegetation characterization”. [14]

6 Analysis and Discussion

6.1 NDVI Index Application on Rabat

The normalized difference vegetation index NDVI [11] is based on the red (R) and near-infrared (NIR) channels. It could be considered as a qualitative tool to assess the environmental quality as it is very sensitive to the quality and the quantity of the ground vegetation [11]. This index calls attention to the distinction between the visible red band and the near-infrared band according to the following formula (NIR-RED)/(NIR + RED). Based on high-resolution satellite imagery, NDVI could also be used as a mapping algorithm and as an technique to distinguish between vegetated and non-vegetated areas. It can also classify densities of vegetation detecting their healthiness and abundance.

The output image of the application of the NDVI index on the city of Rabat (Fig. 7), is acquired on 07.2022, processed by Sentinel a2 and visualized in Python which is an open-source programming language. The NDVI values shown on the map are between −1 and + 1. Negative values from 0 to −1 are corresponding to the surfaces that contain no vegetation like water surfaces, constructions bare soils, etc., for which the reflection in the red is higher than that of the near-infrared.

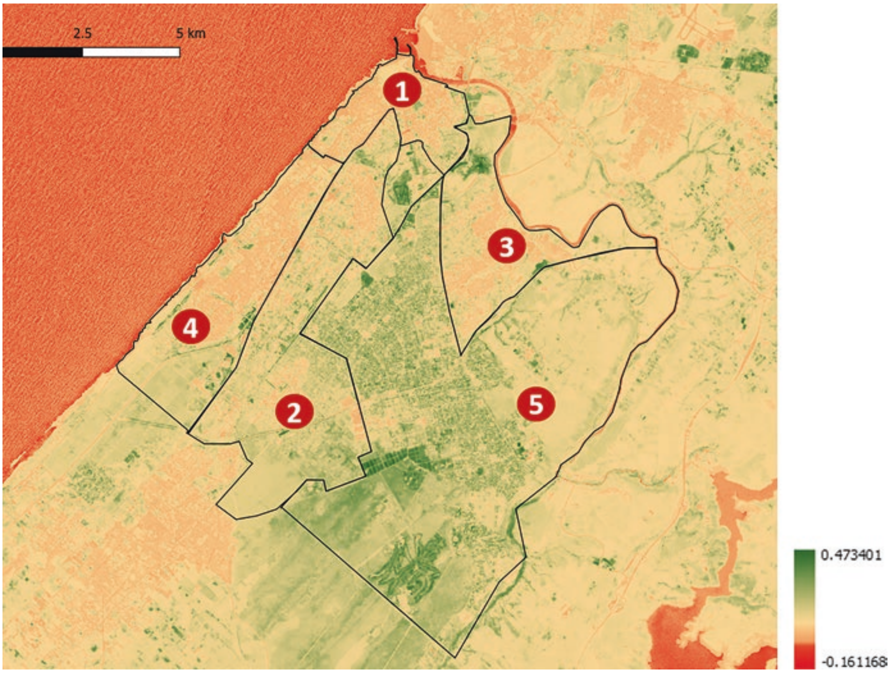


Fig. 7 Output_NDVI index application on the city of Rabat, acquired on 07.2022, processed Sentinel a2_ visualized in Python

The vegetated areas have positive NDVI values commonly from 0.1 to 0.7 represented in green color in the generated map. The highest values for 0.7 to 1 are corresponding to abundant and highly dense vegetation covers. It can be easily seen in the figure that commune 5 (Suissi District) followed by commune 2 (Agdal Ryad) scores the highest values of the NDVI with the densest vegetation covers however the NDVI values are low in the northern part of the city and the industrial zones when the built density is known to be high, in both communes 3 and 4 (Youssoufia and Yacoub El Mansour). The Commune 1 (Hassan district) scores between −0.25 and +0.75 ranking in the third position.

6.2 EVI Index Application on Rabat

The Enhanced Vegetation Index (EVI) is also very similar to NDVI. However, this index takes into account the atmospheric disturbance and influences and vegetation background signal. In areas where the vegetation covers are abundant, EVI does not get saturated as NDVI. Both vegetation indices, generated at 16-day intervals and at multiple resolutions, give an overall consonant spatial comparison of vegetation quality according to its degree of greenness and green canopy external shape and structure.

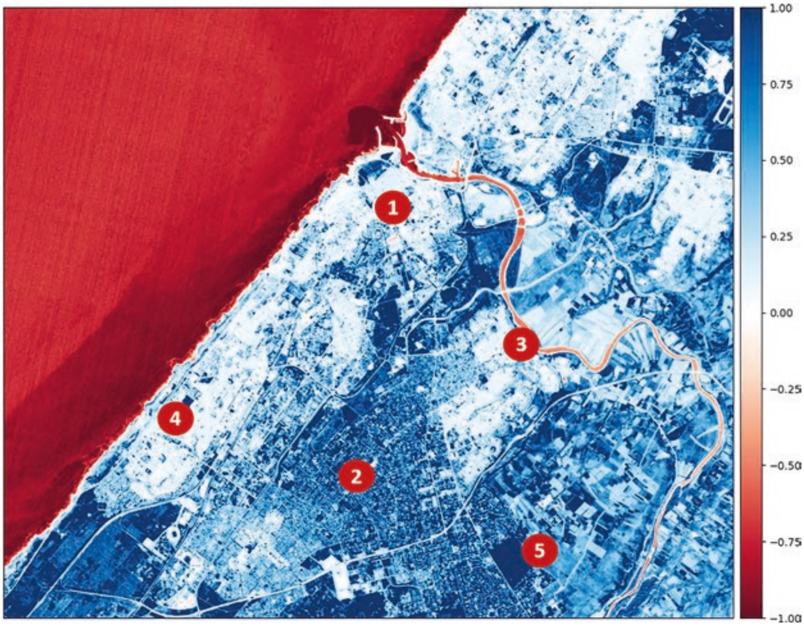


Fig. 8 Output_EVI INDEX- the City of Rabat_ Acquired on 07.2022, processed Sentinel a2_ visualized in Python. Formula: EVI = 2.5*(NIR − RED) / (NIR + 6*RED − 7.5*BLUE +1)

The output of the application in the case of Rabat (Fig. 8) shows the different values in the 5 communes. The value range for EVI is from −1 to +1 when healthy and abundant vegetation covers values vary between 0.2 and 0.8. Commune 5 and 2 (Suissi, Agdal-Riad) corresponding to parks and villa zones, are scoring the highest values of the EVI index indicating better environmental quality than communes 3, 4 and 1 corresponding to industrial and highly dense urban areas.

6.3 VARI Index Application on Rabat

VARI index is also a vegetation index that corresponds to "The Visible Atmospherically Resistant Index" which allows to make an estimation of vegetation fraction in a wide variety of environments with only the part that is visible in the spectrum. While minimizing the lighting differences and atmospheric influences. The calculation of the VARI index values is based on a multiband raster object converting it with the index values according to the following formula: VARI = (Green − Red) / (Green + Red – Blue) where Green corresponds to the pixel values from the green band, Red corresponds to the pixel values from the red band and Blue corresponds to the pixel values from the blue band.

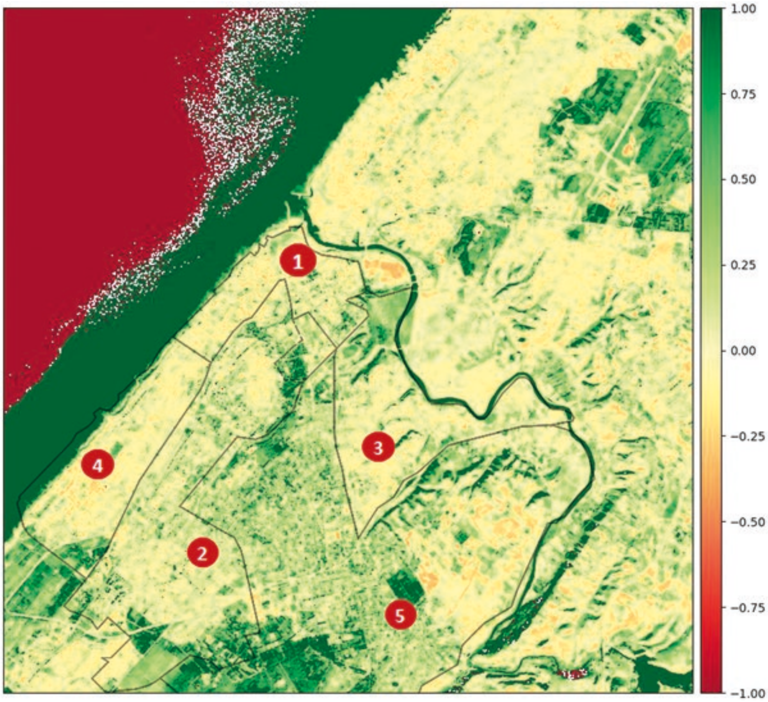


Fig. 9 Output VARI index-generated image, Rabat, Morocco. Acquired on 07.2022, processed Sentinel a2_ visualized in Python

The value range for VARI is from −1 to +1 presenting the estimation of vegetation cover values. The visualization of VARI values for the city of Rabat (Fig. 9) reveals the following results: Commune 1: −0.17, Commune 2: 0.32, Commune 3: +0.03, Commune 4: −0.12, and Commune 5: +0.37. These values exhibit a strong correlation with the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), affirming the findings of previous indices values that commune 5 and 2 offer better environmental quality in terms of green space than commune 1 and communes 3 and corresponding to the lowest values of VARI, NDVI and EVI indices.

7 Results

The results of the analysis illustrate a clear and concise summary of the environmental and urban green space quality of the studied communes in Rabat. These results are based on scientific measures obtained from the analysis of remote sensing data using three environmental indices. These indices are specifically designed to assess the health and condition of vegetation in the respective areas. It provides valuable information about the quantity and state of vegetation in each commune. The values have been normalized to a scale ranging from −1 to 1. Four classes were defined to classify the five communes: "Very good" for values between 0.4 and 1; "Good" for values between 0.20 and 0.40; "Moderate": for values between 0 and 0.20; and "Poor" for values between 0 and −1. This normalization process allows for easier interpretation and comparison of the results across different studied areas. The assessment of environmental quality based on the calculated indices yields the following results for the respective communes in Rabat: Commune 1 (Hassan): NDVI 0.12, EVI 0.11, VARI −0.17, *score: +0.02*; Commune 2 (Agdal-Riad): NDVI 0.28, EVI 0.57, VARI 0.32, *score: +0.39*; Commune 3 (El Youssoufia): NDVI -0.21, EVI 0.06, VARI 0.03, *score: −0.04*; Commune 4 (Yacoub El Mansour): NDVI −0.18, EVI 0.10, VARI −0.12, *score: −0.06*; Commune5 (Suissi): NDVI 0.41, EVI 0.63, VARI 0.37, *score: +0.447*. These results further validate the findings that Commune 5 (very good) and Commune 2 (good) demonstrate a higher level of environmental quality, corresponding to villa zone and large green spaces and parks. Conversely, Commune 1 (moderate) exhibits a moderate level of environmental quality, while Communes 3 and 4 (poor) score the lowest values due to their industrial and densely urbanized nature. Notably, these two communes display the lowest values across the VARI, NDVI, and EVI indices. The environmental indices used in the analysis capture various aspects of vegetation health and quality. By considering multiple indices, a comprehensive understanding of the environmental and urban green space quality in each commune can be achieved.

8 Conclusion

In summary, this paper highlights the advantages of GeoAI in the era of digital transformation presenting a methodological framework to evaluate and give an overall estimation of green space quality and density focusing on the city of Rabat, proving that the geospatial artificial intelligence (GeoAI) using the power of satellite imagery can be a powerful tool to enhance sustainability. Rather than conventional methods which are time-consuming, GeoAI techniques can be very efficient, and cost-reducing. Urban planners, however, should collaborate and work together with the data science community to work on geospatial common issues. As this requires an advanced level of computational science knowledge in parallel with critical and analytical skills.

The result can be as a methodological framework for decision makers to access urban environmental quality based on the integration of vegetation-related indicators derived from remote sensing data to help think about an innovative city planning that improves the quality and efficiency of green space in urban areas enhancing the quality of life and ensuring environmental sustainability.

References

1. Tekouabou, S. C. K., et al. (2021). Reviewing the application of machine learning methods to model urban form indicators in planning decision support systems: Potential, issues and challenges. *Journal of King Saud University - Computer and Information Sciences, 34*(8), 5943–5967.
2. Triantakonstantis, D., & Mountrakis, G. (2012). Urban growth prediction: A review of computational models and human perceptions. *Journal of Geographic Information System, 4*, 555–587. https://doi.org/10.4236/jgis.2012.46060/
3. Xinyu, X., & Ziyu, T. (2020). *A machine learning-based method for predicting urban land use conference: CAADRIA2020*.
4. Gavrilova, Y. (2021). Convolutional neural networks for beginners. https://serokell.io/blog/introduction-to-convolutionalneural-networks
5. Al-Garadi, M. A., Mohamed, A., Al-Ali, A. K., Du, X., Ali, I., & Guizani, M. (2020). A survey of machine and deep learning methods for internet of things (iot) security. *IEEE Communications Surveys and Tutorials, 22*(3), 1646–1685.
6. Jordan, M. I., & Mitchell, T. M. (2015). Machine learning: Trends, perspectives, and prospects. *Science, 349*(6245), 255–260.
7. Alastal, A., et al. (2022). GeoAI technologies and their application areas in urban planning and development: Concepts, opportunities and challenges in Smart City (Kuwait, study case). *Journal of Data Analysis and Information Processing, 10*(2), 110.
8. Eddajjani, A., Hanane, S., Kandry, A. E. et al. (2022). An unexpected presence in urban environment: Factors governing occurrence of the vulnerable European turtle-dove (Streptopelia turtur) in the city of Rabat, Morocco. *Urban Ecosyst 25*, 1339–1351. https://doi.org/10.1007/s11252-022-01234-7
9. Rondeaux, G., Steven, M., & Baret, F. (1996). Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment, 55*(2), 95–107. https://doi.org/10.1016/0034-4257(95)00186-7
10. Huete, A. R. (1988). A Soil-Adjusted Vegetation Index (SAVI). *Remote Sensing of Environment, 15*(1), 295–309.
11. Gitelson, A. A., Merzlyak, M. N., & Lichtenthaler, H. K. (1996). Detection of red edge position and chlorophyll content by reflectance measurements near 700 nm. *Journal of Plant Physiology, 148*(3–4), 501–508. https://doi.org/10.1016/S0176-1617(96)80285-9
12. Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., Ferreira, L. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment, 83, 195–213. https://doi.org/10.1016/S0034-4257(02)00096-2
13. Gitelson, A., et al. (2002). Vegetation and soil lines in visible spectral space: A concept and technique for remote estimation of vegetation fraction. *International Journal of Remote Sensing, 23*, 2537–2562. (ESRI, 2018).
14. Kamenova, I., & Dimitrov, P. (2021). Evaluation of Sentinel-2 vegetation indices for prediction of LAI, fAPAR and fCover of winter wheat in Bulgaria. *European Journal of Remote Sensing, 54*(sup1), 89–108. https://doi.org/10.1080/22797254.2020.1839359

Living Lab for Technological Retrofit Design on Perceived Quality

Antonella Violano, Nicola Barbato, Monica Cannaviello, Gigliola D'Angelo, and Martina Pezzuti

1 Introduction

"I think of school as an environment of spaces where it is good to learn" said Louis Kahn, indirectly justifying the importance of interpreting the relationship between the potential offer of building comfort and the real demand of psycho-physical well-being for the direct users.

However, the meeting point between supply and demand is not always within the realm of possibility. In cases where this point is not in equilibrium, it is necessary to intervene with technological design solutions that improve the performance of the existing building system or integrate it with new materials, components, or technological units able to achieve "Possible Quality" objectives. These objectives arise from a complex design approach that skillfully combines compositional and construction knowledge, orienting choices not only on the basis of available resources and needs but also on the eco-compatibility of the proposed transformations and the efficiency that can be achieved during operation. Especially in retrofit design, in which the building does not change its use, the approach of "Possible Quality" ensures not only that the synergistic relationships between the environment and the building are respected, but also that the potential supply of the building system intersects with the demand of direct users, according to rationality motivated by the needs of perceived comfort. In fact, the project, before being a tool of transformation, is a tool of knowledge. Building construction requires the creative interpretation of the needs of direct users: a wise balance between technological innovation,

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research and "Possible Quality." The MedEcoSuRe research proposes a pragmatic approach to innovation (ICT), characterized, among other things, by experimentation involving the real and active involvement of direct users (human-environmental centered design). This is feasible through the implementation of the "LIV:ing Lab" (Violano et al., 2021) [1], that the Vanvitelli University is planning to join the BEXLab (Mediterranean Cross border Living Lab) network.

The conceptual prerequisite is that it is not enough to make an efficient architectural design; it is important to test the choices and be able to assess whether the solutions need to be changed.

The research design tested the concept of "Energy Friendly Retrofit," which focuses not on the end result but on the process that leads to it. Through energy participatory design actions (Energy Living Lab), the retrofit is based on people and their ability to communicate their specific perceived comfort conditions to improve building services and performance. The method tested gives direct users the opportunity to make judgments about both the building's performance (Hardware system) and the way spaces are used (Software system). In addition, the monitoring of learning experiences on energy-environmental issues led to the definition of procedures for using learning spaces consistent with the goals of maximizing comfort and minimizing resource use. The salient features of the research project and the conducted experimentation of energy-participatory design are outlined below.

2 The Cultural and Strategic Background

The political and cultural context in which the research activities of the MedEcoSuRe project are embedded is complex and characterized by continuous innovation of objectives leading to a gradual transition to more sustainable scenarios. The urgent need to tackle climate change by reducing building-related emissions is clearly highlighted in the European Green Deal, the roadmap that should help Europe achieve climate neutrality by 2050. In this context, the Renovation Wave (A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives COM/2020/662 final), a strategy put in place to encourage the energy retrofitting of existing buildings, is aimed not only at reducing emissions but also at improving the quality of life of the people who live in and use buildings. Indeed, the goals of energy efficiency and comfort cannot be pursued separately, but a holistic approach is needed to achieve truly sustainable results. One of the priorities of the Renovation wave strategies, which aims to double annual energy renovation rates in the next 10 years, is the renovation of public buildings. A key starting point must be the energy efficiency of buildings with high occupancy rates, such as universities. Considering that educational buildings account for 17% of non-residential buildings in the European Union, they provide an interesting opportunity to create examples of integrated renovation actions, which address functional and energy aspects in a joint vision [1].

Universities are also important nodes in global networks, connecting cities and nations through teaching and research projects, and can be regarded as important urban players with a direct impact on society.

Further factors driving toward the redevelopment of university buildings include the educational function they perform, and above all the possibility of using them as living laboratories for higher education [2].

The New European Bauhaus was born out of the desire to make the Green Deal a cultural experience, tangible and shared by European citizens with the aim of building a new future together; the focus is on collaboration and the exchange of ideas between designers, students, citizens, businesses, public administrations, with the aim of 'participatory design'. The proposed approach to the retrofit project, which is that of the living lab, is consistent with the New European Bauhaus objective of bringing together citizens, experts, businesses, and institutions together to reimagine sustainable living in Europe and beyond (https://new-european-bauhaus.europa.eu/about/about-initiative_en).

This is the political and cultural frame of reference of "Mediterranean University as Catalyst for Eco-Sustainable Renovation" (MedEcoSuRe), a project funded by the European Union, under the ENI CBC MED programme.

3 The MedEcoSuRe Project

MedEcoSuRe project is rooted in the key role that Mediterranean universities have to contribute to environmental development and combat climate change. The project brings together researchers and stakeholders to build a common understanding of the eco-sustainable building renovation issues and aims to empower the regional knowledge-to-action process, starting with the university's immediate neighborhood, which is the university building.

The research we are carrying out aims to assess the sustainability of university buildings, and in order to define the boundary conditions, we analyzed the international strategies that improve both the energy performance of buildings and the quality of life of people who use university buildings.

One of the main results of the project is the definition of the BEXLab (Mediterranean Cross border Living Lab) network. The living lab stands as an incubator and space for analysis and experimentation; it is a research environment embedded in real life and involves users in the innovation process [3].

The research group of the University of Campania, as one of the Associated Partners of the project, actively collaborated with ANEA by organizing a Design Workshop on "The evaluation of the energy performance of existing school buildings" (WP2) and specialized seminars that focused on policy and design tools for energy efficiency retrofits in higher education buildings (WP4). The proposed methodology considers, on the one hand, the evaluation of physical parameters by first considering the known minimum requirements as per regulations through tools and software that verify them and return a result in terms of building performance that falls within the measured and calculated quality.

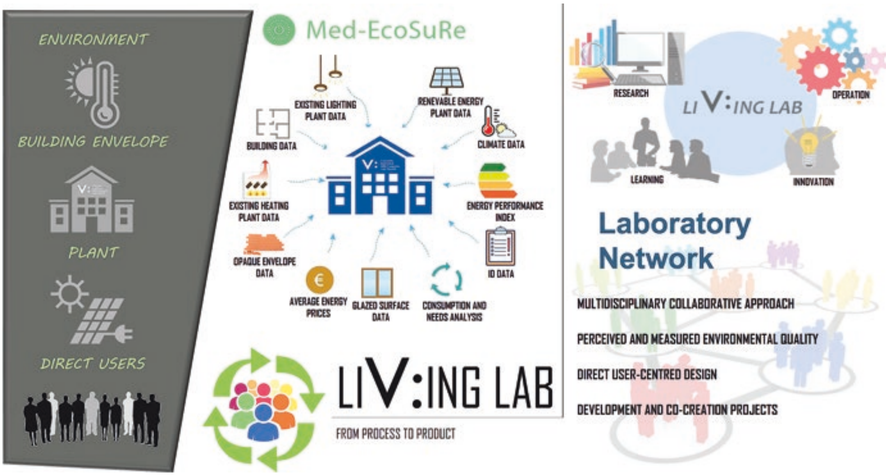

Fig. 1 LiV:ing Lab Design process

However, the concept of innovation is to combine the assessment of quality, measured and calculated through standard methods and compliance with minimum legal requirements, with the evaluation of another quality parameter: the perceived quality. Perceived quality has an evaluation method based on the response of users who communicate needs and feelings and give indications that the designer then transforms into design actions and strategies. In the specific case of this research, Living Lab Vanvitelli invites students to be an active part of the design so that through interviews and questionnaires, they can really say how they experience environments. This practice, which is embodied today in the LivingLab, comes from an experimentation that goes way back, developed over the years by the research team and proposed in national and international contexts [4].

Thus, the implementation of the LiV:ing Lab represents an effective strategy to ensure sustainability of Vanvitelli University, through users' awareness of their surroundings and how they relate to this, making them participants in the design process, Fig. 1.

4 Comfort: Conditions and Performance of Eductional Buildings

The starting point is the assessment of the comfort conditions of indoor spaces and the synergistic and/or conflicting relationships with the external environment. The improvement of links between energy-environmental performance, perceived comfort and direct user behavior is of great importance in this project.

Starting from the analysis of best practices such as the School of the Future project carried out from 2011 to 2016, which produced guidelines on indoor environmental quality in schools with respect to four case studies in four countries [5], a methodology based on the evaluation of physical comfort parameters (visual, thermal, acoustic, air quality) was developed to arrive at the condition of psychophysical well-being. Regarding visual comfort, without prejudice to the principles of artificial lighting defined by UNI 10380, UNI 10840 provides the requirements to ensure optimal conditions for both artificial and natural lighting, in fact, especially for educational buildings, it is essential to consider the balance between natural light and artificial lighting, which is strongly influential in improving cognitive performance.

By working on the existing building, it is possible to optimize this balance through the use of smart systems and sensors that reproduce natural light conditions by controlling, for example, the intensity and color temperature parameters, or by modulating the lighting according to the intended use of the rooms based on human perception. This translates into the HCL – Human Centric Lighting method, which considers the need for a particular lighting condition at various times of the day based on the three spheres of influence of light: visual, emotional and biological, and thus considering the improvement of visibility and orientation for the safety of users, the improvement of mood and the influence on the circadian rhythm.

Talking about comfort also means taking into account safety; noise pollution plays an important role and is therefore always evaluated as an environmental risk in all work areas. For the school sector, UNI 11532-2 defines the limit values of various parameters, including reverberation time and system noise in confined educational spaces; when assessing acoustic comfort, it is essential to consider these factors, which affect so-called background noise that, if not strongly taken into account, can lead to conditions of general discomfort with a consequent negative influence on performance and often also on the development of cognitive abilities linked to specific learning disorders [6]. In addition to the noise risk, among the physical factors to be considered, there is the risk related to "thermal stress" in relation to the microclimate of the environment [7], this risk can be averted by aiming to achieve thermo-hygrometric well-being, i.e. "the mental condition of satisfaction with the thermal environment" [UNI ISO EN 7730]. According to the Fanger model, developed in the 1960s, comfort indices are a function of indoor conditions (temperature, relative humidity, airspeed, mean radiant temperature), clothing and metabolic rate; these indices PMV (Predicted mean vote) and PPD (Percentage People Dissatisfied) respectively represent the average comfort condition, expressed on the ASHRAE thermal sensation ranging from −3 "very cold" to +3 "very hot", where 0 is the ideal value, and the percentage of dissatisfied people (considering a 10% assumed dissatisfaction) The six variables are then acted upon to avert thermal discomfort conditions [8].

Finally, it is crucial to consider indoor air quality to ensure the IAQ (Indoor Air Quality) standard codified by ASHRAE. In fact, problems in the heating system, inadequate air conditioning and ventilation systems, or the non-application of maintenance programmes, lead to a high concentration of chemical or biological compounds that, after a few hours inside an environment, can cause feelings of physical

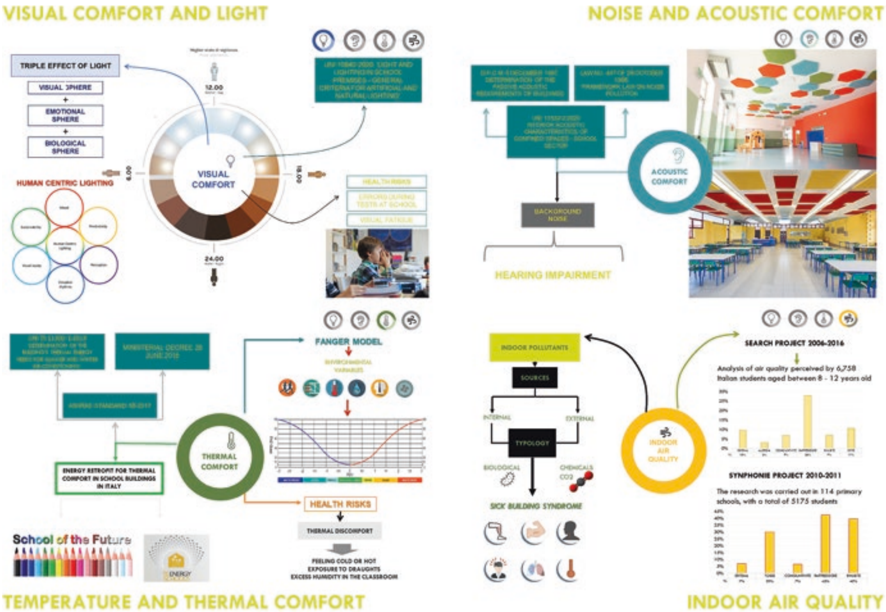

Fig. 2 Parameters for evaluating: (**a**) visual, (**b**) acoustic, (**c**) thermal, (**d**) indoor air quality comfort conditions

and psychological discomfort known as sick building syndrome, causing among other things a decrease in productivity. Through the adoption of good strategies and sensors for air exchange through natural ventilation or forced ventilation systems, it is possible to measure and guarantee acceptable parameters of concentration of compounds (such as CO_2).

The "Energetically Friendly Retrofit" concept design involves the application of different eco-oriented technological solutions, harmoniously integrated to achieve a linguistic-formal and functional unity that arise from a critical transition to sustainability implemented through a shared mission between built heritage management, research, and education [9], *see* Fig. 2.

5 First Phase of LiV:ing Lab: "Real Quality" Analysis

The analysis of the "Real Quality" of the educational building, understood as an objective assessment of energy and environmental performance calculated with software consistent with current regulatory requirements, and/or measured through the use of standard tools and techniques, represents the first phase of the proposed methodology. According to the European regulatory framework on the energy performance of buildings (Directive 2018/844/EU), the comparison between the analyzed building and the Reference Building should provide all the indicators needed to assess whether a building is an energy and environmentally sustainable. However, it needs to be understood whether this approach is also appropriate for assessing indoor environmental quality (IEQ), the maintenance of which should be *a key priority in educational buildings* [10]. Most studies conducted on academic buildings tend to analyze either energy performance or comfort issues, but few research simultaneously address and investigate the links between energy audits, IAQ assessment and thermal comfort assessment, particularly in Western European countries [11, 12]. On the opposite, it is believed that, precisely in educational buildings, the close relationship between energy performance and IEQ should be deepened, not only through calculations and measurements but through the involvement of direct users throughout the process of evaluation and identification of passive technological retrofit solutions. Although the assumption of this contribution is that the indicators provided by the legislator are not sufficient in themselves to guarantee the control of indoor environmental quality (IEQ) in educational buildings, they are nevertheless a mandatory requirement and must therefore be verified.

The Living Lab experimentation was conducted in the "E. Sereni" High School in Cardito (Naples) and it included the involvement of all the direct users (students, teachers, technical-administrative staff) and stakeholders in the elaboration of the "Participatory Energy Audit" [13].

However, a preliminary theoretical and practical training activity was necessary, on the relationship between architecture and climate, building energy performance and comfort, to prepare the students to face the activities of criticality analysis and identification of passive retrofit solutions in the living lab (Fig. 3). The experimental work carried out showed that, in educational buildings, starting from an Energy Audit in compliance with UNI CEI EN 16247 technical standards, carried out by

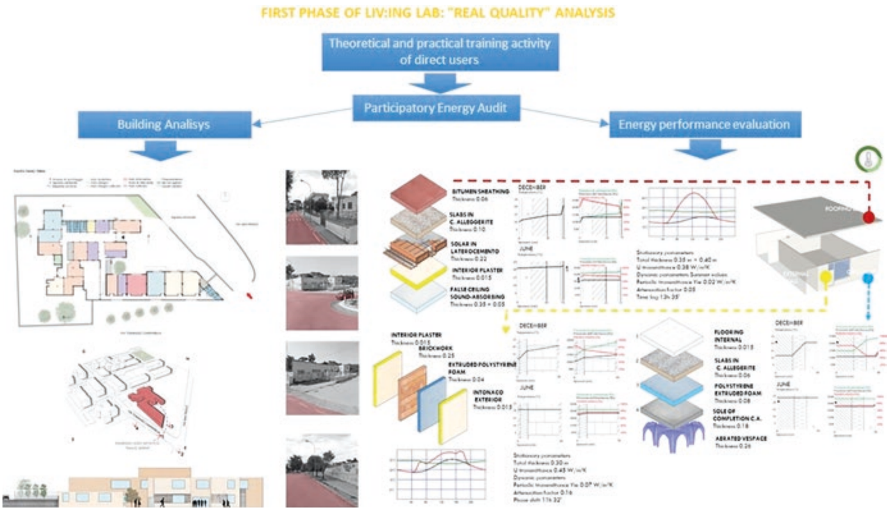

Fig. 3 First phase of LiV:ing Lab "Real Quality" analysis, tested on the "E. Sereni" High School

the Auditor with the involvement of direct users, suitably trained, can provide an initial evaluation of the building's Energy Footprint gets to redesign the whole system, or parts of it, through conscious building-user interaction [14].

The analysis of the asset rating performance of the building-plant system and especially of the envelope, which led to the development of specific indicators, served as a starting point for a cross-comparison with the analysis of perceived quality (user surveys carried out in the second phase of the living lab). After assessing the energy performance of the entire building, the experimentation focused on a classroom that is part of an extension to the school complex built in 2003, which is in a fairly good state of preservation but shows, especially on the sound-absorbing ceiling, signs of infiltration, interstitial condensation and mould.

The performance calculation of the opaque envelope showed that despite the presence of external insulation, the thermal transmittance values required today for the reference building were not achieved. Instead, the requirements for thermal inertia (periodic thermal transmittance, time lag and decrement factor) were met. The assessment of condensation and mould growth risk did not find the presence of surface and/or interstitial condensation on any of the opaque components, but the actual situation as found on site and described by the direct users made it necessary to investigate further to identify the causes of the performance deficiencies. On the other hand, studies have found that not only is there often a large gap between calculated and actual energy consumption in such buildings, but the worst aspect is that comfort conditions are not guaranteed due to various problems such as improper installation, poor quality materials and poor quality control [15].

6 Second Phase of Liv:Ing Lab: Perceptive Analysis for Technological Retrofit Design

To promote a methodology that put students in the center as actors and spectators of the retrofit actions, the research implemented the Living Lab tool as a "research methodology to identify, prototype, test and refine complex solutions in real-life, multiple and evolving contexts". (William Mitchell – MIT Media Lab).

Living Labs are end-user-centered Open Innovation ecosystems, based on a multidisciplinary approach, for research and innovation in real-life processes [16]. In the experimentation conducted with students and teachers of "Emilio Sereni" High School, there were essentially four phases of Living Lab implementation with students in class 3C:

1. Technological analysis of the space: a site survey was carried out in order to identify the main features of the school building and the classroom in which the 3C students conduct their lessons. Then, a thermohygrometric and lighting assessment of the physical conditions of the classroom was performed for the analysis of comfort and environmental quality;

2. Perception design, i.e., the direct user needs analysis: direct users, their needs and habits, as well as usage rates and time/mode of use of spaces were identified. This phase focused on sharing and including all actors and stakeholders in meetings and classes through the use of online communication platforms, such as Google Meet. Interviews and questionnaires were conducted to share classroom needs and issues, resulting in the identification of priorities for improving perceived comfort conditions;
3. Design Prototype: a collection of ideas and opinions from the different categories of actors and stakeholders involved, for the design of a comfortable classroom. The purpose is to obtain a clear picture of the stakeholders that allows improvement actions to be calibrated to the real needs for an appropriate final project development strategy.
4. Action: that is, the technological and design organization of the results obtained, the structured comparison between the calculated/measured data and the users' statements about perceived comfort for the identification of the final design.

By collaborating and thinking together about solutions, the students, as stakeholders, reduce the degree of complexity and uncertainty about what should be the best choice to implement, thus increasing the possibility of finding a sustainable solution (STARS approach).

The methodology had already been partially tested as part of the "Resilient Schools" research project [17], in which the technological retrofit concerning the improvement of energy and environmental performance of school buildings analyzed in the province of Naples and Caserta, highlights the need to take the conceptually strategic step of comparing "Real Quality," measured through the use of standard tools and techniques with reference to minimum requirements established by mandatory laws, and "Perceived Quality" by direct users, who experience school spaces and perform the intrinsic mediation between well-being and lived space [18]. Through the Living Lab, the essence of which is sharing and participation, end users can freely express themselves about their needs and expectations through data collection methods, questionnaires and tests.

Meetings with the School Headmaster, professors and 3C class students served to explore issues and manifest needs in order to initiate a process of co-creating the ideal comfortable space through the sharing of needs and goals summarized in the Living Lab exercise.

The meetings allowed for an open dialogue with students and teachers on the importance of knowledge of measurable physical parameters, technical tools to calculate compliance with legislative requirements, and the search for technological and behavioral solutions according to the Open Innovation approach [19]. In addition, the school building in the project is conceived as an "Educating Building" in which direct users assimilate "sustainable living" as a multi-scalar systemic approach: from materials to components, from the building organism to the environmental ecosystem, experiencing a real "Technological Intelligence" that is not limited to technically managing the relationship between needs, requirements and performance, but controls the design process with a participatory approach (Living Lab), which goes beyond the mere instrumental control of physical parameters [20].

The involvement of the actors through the analytical and implementation tool of the “living lab” for an environmentally, energetically and socially renovated building ensures what can be called a Participatory Energy Design. In order to promote a methodology that places students and teachers at the center as actors and spectators of retrofit actions, living labs will be the solution for such a process as producers of knowledge. The potential for technological and energy retrofit, investigated in this experimentation and deepened and structured in the MedEcoSuRe project, is implemented through fundamental actions, in line with the criteria set forth in the European Green Deal: from improving the efficiency of the building-plant system to optimizing maintenance and operating costs. School spaces, thus renewed in their role as educational hubs, become civic centers or social incubators in which such actions are engines for urban regeneration of areas lacking adequate services and social infrastructure.

7 Conclusion

Starting from the concept that a University is “a place where circulate ideas and bring innovation projects to life towards a sustainable, creative and inclusive future’, the research project proposes the creation of a Living Lab where we can have a multidisciplinary collaborative approach, new learning processes, subject-object users and development and co-creation projects. The methodology adopted in this research project requires technology choices to be based not only on the rational use of available resources but also on the expressed needs and eco-friendliness of the proposed transformations, which are analyzed in the operational rating for the retrofit of the existing building.

Therefore, if the technological design is a decision-making process, which decisions have the greatest impact on the sustainability of the technological design?

If the technological design is an interdisciplinary work (thinking Vitruvius!), what tools and information are needed to make more conscious decisions?

If the construction process has stages characterized by different actors and aims, when and with whom should these decisions be made?

In the design process, making shared decisions with direct users can help achieve significant results in efficient land use, energy consumption, water savings, and eco-sustainable materials, but above all, it enables significant results in terms of comfort and well-being with minimal resource consumption. At this historical time, characterized by a coming and hard-to-control energy crisis, satisfying the needs of direct users with minimal resource consumption without making energy sacrifices is the first of the goals. New design production models redefine the powers of the technology industry for innovation by introducing process management tools such as living labs. Creativity and courage are needed in some cases, awareness and sensitivity in others, but in both cases, there can be no technological innovation without behavioral innovation. My invitation is always the same: Let’s change the design method!

So we will help improve the quality of places not by transforming things, but the way we use them.

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References

1. Österreicher, D., & Geissler, S. (2016). Refurbishment in educational buildings – Methodological approach for high performance integrated school refurbishment actions. *Energy Procedia, 96*, 375–385.
2. Ming, H. (2018). Optimal renovation strategies for education buildings—A novel BIM–BPM–BEM framework. *Sustainability, 10*(9), 3287. https://doi.org/10.3390/su10093287
3. Kåreborn, B., Eriksson, C.I., Ståhlbrost, A., & Svensson, J. (2009). A milieu for innovation: Defining living labs. In *ISPIM innovation symposium proceedings*, Svezia. Available on: https://www.researchgate.net/publication/228676111_A_Milieu_for_Innovation-Defining_Living_Labs
4. Fumo, M., Cennamo, C., D'Angelo, G., Izquierdo, P. C., Lopez-Izquierdo, P., Palmero, P., & Violano, A. (2020). Interdisciplinary and international workshop as technological design method focused on the European Ods strategy. In *14th annual international technology, education and development conference, INTED2020*.
5. Steiger, S., Park, S., Erhorn, H., & de Boer, J. (2014). *Retrofit guidelines towards zero emission schools with high performance indoor environment*. EU project School of the Future.
6. Clark, C., Martin, R., van Kempen, E., et al. (2006). Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: The RANCH project. *American Journal of Epidemiology, 163*(1), 27–37.
7. D.Lgs. 81/2008 – Testo unico sulla salute e sicurezza sul lavoro (Allegato IV; Requisiti dei luoghi di lavoro, 1. Ambienti di lavoro,1.9 Microclima.
8. ANSI/ASHRAE Addendum d to ANSI/ASHRAE Standard 55-2017.
9. Alonso-Almeida, M., Marimon, F., Casani, F., & Rodriguez-Pomeda, J. (2015). Diffusione del reporting di sostenibilità nelle università: situazione attuale e prospettive future. *Journal of Cleaner Production, 106*(2015), 144–154. https://doi.org/10.1016/j.jclepro.2014.02.008
10. Ulpiani, G., Nazarian, N., Zhang, F., & Pettit, C. J. (2021). Towards a living lab for enhanced thermal comfort and air quality: Analyses of standard occupancy, weather extremes, and COVID-19 pandemic. *Frontiers in Environmental Science, 9*, 725974. https://doi.org/10.3389/fenvs.2021.725974
11. Merabtine, A., Maalouf, C., Waheed Hawila, A. Al., Martaj, N., & Polidori, G. (2018). Building energy audit, thermal comfort, and IAQ assessment of a school building: A case study. *Building and Environment, 145*, 62–76. ISSN 0360–1323. https://doi.org/10.1016/j.buildenv.2018.09.015
12. Allab, Y., Pellegrino, M., Guo, X., Nefzaoui, E., & Kindinis, A. (2017). Energy and comfort assessment in educational building: Case study in a campus universitario francese. *Energy and Buildings, 143*(2016), 202–219. https://doi.org/10.1016/j.enbuild.2016.11.028

13. Violano, A., Ibrik, I., & Cannaviello, M. (2021). Progettazione incentrata sull'uomo: retrofit energetico partecipato per gli edifici scolastici. *Sustainable Mediterranean Construction (SMC) Journal, 13*(2021), 106–116.
14. Alshuwaikhat, H. M., Abubakar, I. R., Aina, Y. A., Adenle, Y. A., & Umair, M. (2017). Lo sviluppo di un modello basato su GIS per la valutazione della sostenibilità ambientale dei campus. *Sostenibilità, 9*(3), 1–23. https://doi.org/10.3390/su9030439
15. Gupta, R., & Gregg, M. (2016). Empirical evaluation of the energy and environmental performance of a sustainably-designed but under-utilised institutional building in the UK. *Energy and Buildings, 128*, 68–80. https://doi.org/10.1016/j.enbuild.2016.06.081
16. Chesbrough, H., Vanhaverbeke, W., & West, J. (2008). *Open innovation: Researching a new paradigm*. Oxford University Press.
17. Fumo, M., Ausiello, G., & Buanne, M. (Eds.). (2018). *Verso una scuola resiliente*. Luciano Editore.
18. Ballon, P., & Schuurman, D. (2015). Laboratori viventi: concetti, strumenti e casi. info. 17. https://doi.org/10.1108/info-04-2015-0024
19. West, J., Salter, A., Vanhaverbeke, W., & Chesbrough, H. W. (2014). Open innovation: The next decade. *Research Policy, 43*(5), 805–811. Available on: https://www.researchgate.net/publication/261834881_Open_Innovation_The_Next_Decade
20. Evans, J., Jones, R., Karvonen, A., Millard, L., & Wendler, J. (2016). Living lab and co-production: University and campuses as platforms for sustainability. *Current Opinion on Environmental Sustainability, 16*, 1–6.

Part VI
Late Arrival Papers

Retrofitting of an Existing Building to Be a Sustainable, Vibrant, and Smart Building

Rana Samir, Lamyaa Gamal, Simone Prospero, Pietro Durantini, Chiara Cappucci, Giuseppe Muliere, Abdelrahman Mohamed, and Mohsen Aboulnaga

1 Introduction

Cities and buildings have a significant impact on the environment and climate change through the consumption of natural resources, carbon emissions and waste generation. Buildings account for about 40% of global energy consumption and about a third of global greenhouse gas emissions. There are 220 million buildings in Europe that depend on fossil fuels and inefficient energy sources for heating and cooling [1]. There is a growing demand for high-performance and sustainable buildings, and therefore improving energy efficiency can contribute significantly to limiting environmental degradation. Buildings globally consume the most energy in heating, ventilation, and air conditioning which is estimated about 35–40% of total building energy. In hot climate, energy consumption can be up to 65% of the total energy use in buildings. To address energy and environmental challenges, it is important to design buildings that meet energy requirements by incorporating renewable, low-carbon and smart technologies and strategies [2]. Research shows that the greenest sustainable building is not necessarily a new one, but an upgrade of an existing one. The US Green Building Council (USGBC) reports that green renovations have been at the top of their list for several years. In last year's Trends 2016 report, the USGBC noted that LEED for Building Management and Maintenance, also known as LEED-EB or EBOM, is the most widely used rating

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system for LEED-certified buildings in the top 10 states. In that year, LEED-EB represented approximately 53% of the total certified area. This year's latest LEED update, version 4.1, was the first system released for use in buildings last March [3, 4].

Urban agriculture (UA) or urban farming (UF) can vastly address the need to grow cities and feed their people. In addition to local food production, UA or UF offers many benefits to communities such as energy conservation, waste management, biodiversity, nutrient cycling, greenhouse gas (GHG) mitigation, economic revitalization, building resilient food systems, human health, social interaction, and education as well as climate change mitigation [5, 6]. Figure 1 *presents the benefits of home gardens and urban agriculture.*

This chapter presents a study conducted on a site in the city of Bologna, Italy in the largest public park in Bologna – Le Serre of Giardini Margherita, which is a Green Spot in the grey of the city and a place that people visit temporarily to move away from everyday life and the chaos of the city. Green Sport is a response to the context of Le Serre of Giardini Margherita and to people who live in the surrounding area, as it will be a green social hub that will host cultural events, educational workshops, and innovative cultivation system and co-working spaces to work and study. Figure 2 *shows the Le Serre of Giardini Margherita.*

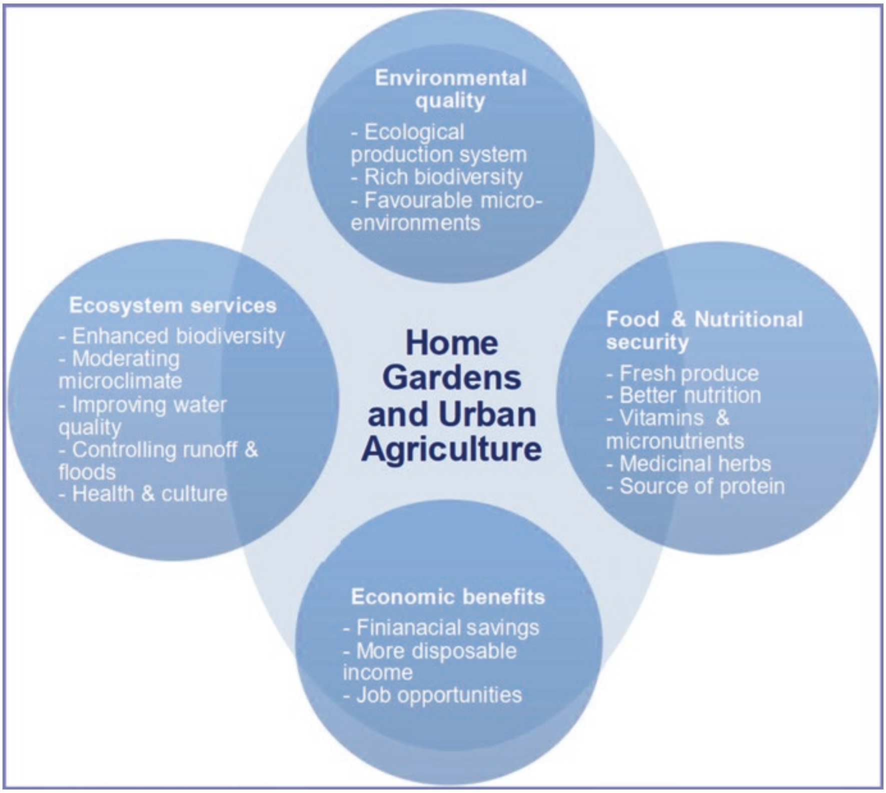

Fig. 1 Food, environmental, economic, and ecosystem service benefits of home gardens and urban agriculture. (Image Source: developed by authors after https://link.springer.com/article)

Fig. 2 Existing situation of Le Serre of Giardini Margherita in Bologna, Italy. (**a**) Front view of the garden. (**b**) General view. (**c**) Arial of the old steel structure. (Image source: developed by authors)

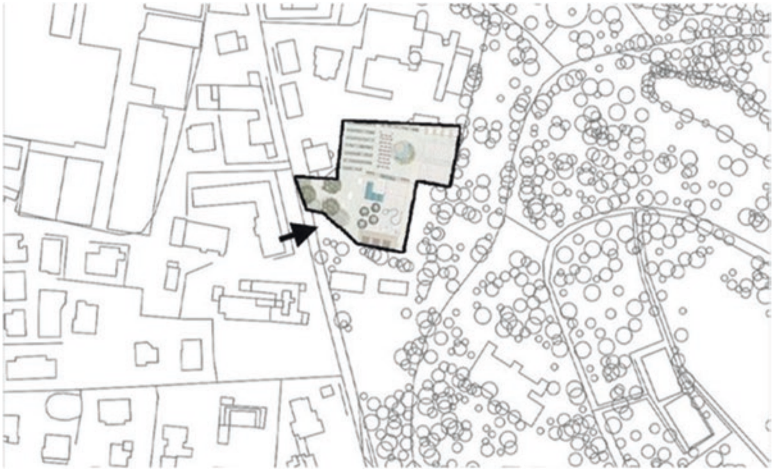

Fig. 3 The site and current proposal highlighted. (Image source: Authors based on Google Maps, 2021)

2 Objectives

There is an urgent need for high-performance and sustainable buildings to improve energy efficiency that contributes significantly in limiting environmental degradation and mitigating climate change. The objectives of the Green Spot project were to improve energy efficiency and minimize the environmental impact of the site (Fig. 3). It also aims to attract people from different backgrounds, interests, and ages, and create a place to raise peoples' awareness about everyday life sustainability, it represents a model of circular economy and sustainability, in which the production of waste will be reduced at its minimum, enhancing agricultural awareness, improve quality of life and using smart systems to preserve energy and water that attain the SDGs, mainly goals 3, 6, 7, 8, 11, 12, 13, 14 and 15 as highlighted in Fig. 4 [7].

Fig. 4 SDGs that Green Spot will achieve. (Image Source: UN Global Compact, 2015)

3 Issues and Challenges

Climate change affects many areas globally as well as impacts our lives. This caused not only severe draughts which led to food safety issues due to high summer temperature, but also destructive floods due to heavy storms in July and August 2022 in London UK; Paris, France; Taxes, USA; and Pakistan, Aisa. Urban agriculture can be a solution to this particular challenge, providing local products using affordable and sustainable modern technologies. Climate change adaptation also requires using more clean energy from renewable energy resources instead of burning fossil fuels.

The site of the study is an existing grey site next to the largest public park in the city of Bologna, Italy – Le Serre of Giardini Margherita. The site is classified with several challenges as follows:

- An existing location with two greenhouses constructed by steel structures that need renovations to be used for several purposes and to be sustainable
- The space lacks services to attract people to use it
- The place needs shelter from heavy rain and storms, which can be a good potential for irritation
- It was a cultural-social hub with many activities before deteriorating

4 Methodology

It was imperative to examine the site from the urban and sustainability aspects including environmental, social, and economic to identify the obstacles and weaknesses and the place's strengths. Based on this, we proposed sustainable solutions on the three axes to put forward liveable, smart, and environmental proposals that have a positive impact on the environment. In pursuing such an approach, site visits, data and information were collected on various levels, including the site, and consulted with the residents of Bologna to better inform the solutions and to know their appropriate character.

5 The Study

The study covers the innovative concept in addition to architectural solutions to provide a sustainable and livable site and smart buildings as well as environmental solutions (water, energy, sustainable material, and waste recycling), agriculture solutions, social intervention and solutions, as well as economic solutions.

5.1 Concept

The concept aims at rethinking the two greenhouses of La Sierra Madre and the aquaponics green houses. The former will be used as recreational and social space, while the latter will serve as productive green houses. Each component of the project works and uses in sync with the others to minimize the environmental impact of the place, this encompasses:

(a) A bio-lake will gather rainwater collected from the rooftops of the greenhouses.
(b) The collected water is used to irrigate the plants in the Nutrient Film Technique (NFT) which is a popular and versatile hydroponics system and Vertical Farm cultivation.
(c) The agricultural products will both be cooked in a VETRO restaurant and used as material for the workshops that will be held in La Sierra Madre.

Therefore, 'Green Spot' represents a model of circular economy and sustainability, in which the production of waste will be reduced to its minimum, and every product and material, will be valued as much as possible.

Green Spot's concept is to link the mind (represented by the co-working space for smart working and the workshop area), soul (represented by the cultural hub for art and concerts), and body (represented by the yoga classes and outdoor activities) together. The project aims to tackle nine "Sustainable Development Goals" (SDGs), determined by the United Nations General Assembly as part of the 2030 Agenda, by implementing the main three pillars of sustainability: economic, environmental, and social aspects. The pursued goals are as follows:

- Goal 3: Good Health and Wellbeing
- Goal 6: Clean Water and Sanitation
- Goal 7: Affordable and Clean Energy
- Goal 8: Decent Work & Economic Growth
- Goal 11: Sustainable Cities and Communities

- Goal 12: Responsible Consumption & Production
- Goal 13: Climate Action
- Goal 14: Life Below Water
- Goal 15: Life on Land

5.2 Architecture Solutions

Regarding the architectural solution, our research work address the main eight issues, including:

1. *Learning Greenhouse:* will be divided into two areas: one will be for kindergarten indoor activities, and the other one will host a co-working space where people can work and study.
2. *Playground:* near the Learning Greenhouse, a playground will be constructed to give kids a space to have fun outside in the sunlight.
3. *Artists' Residences area:* works of art could then be exhibited by the artists to make temporary exhibitions that will contribute to increasing the beauty of the place.
4. *Vertical Cultivation Greenhouse:* this system is suitable to produce leafy veg., micro-greens, and small fruits, tower height is 2 m it will be 10 holes per column
5. *Multifunctional Greenhouse: will* host art exhibitions, a workshop area, and a multifunctional space that can be used according to the needs.
6. *Yoga Zone:* people can attend yoga classes in the summer with a perfect lake view. In case of bad weather conditions, this activity can be done inside the Multifunctional greenhouse, using flexible moving units.
7. *Bio-lake area:* the bio-lake with a platform above it will be used to create a space for studying and working shaded by the Smart Inverted Umbrella.
8. The theatre: outdoor theatre will be realized. It will host music concerts and art performances to make Green Spot more livable and viable

5.3 Environmental Solutions

Nowadays, we live in an increasingly polluted world in which the sustainability of our daily actions becomes more and more critical. Green Spot is an innovative solution that seeks to minimize its environmental impact by trying to encourage the use of sustainable practices. Specifically, Green Spot aims to minimize its impact on water use, energy use, and waste production as well as to mitigate climate change.

5.3.1 Water

The water needs of the aquaponic system will entirely be satisfied by the collection of rainwater. The system of pipes and gutters will collect rainwater from the roof of the social greenhouses and direct it to the bio-lake, to be accumulated. It will be able to contain 230 cubic meters of water, which are sufficient to satisfy the annual water consumption of the plants that grow in the production greenhouse. The dimensions are available on the website of Aquaponic Design [8].

5.3.2 Energy

In terms of energy, Green Spot aims to maximize green energy production, which will mostly come from the use of renewable (solar PV panels). These PV panels will be placed on the roof of the social greenhouse in order to not cause excessive internal shading of the environment. The Inverted Umbrella Structure as shown in Fig. 5 is an innovative technology that collects rainwater and generates renewable energy from the sun.

It is an environmentally-friendly product that aims to reduce energy consumption and carbon emissions. The supporting structure of the Inverted Umbrella occupies a very small surface (0.25 m^2), so it saves energy and space as well [9]. It runs on solar energy thanks to the solar panel installed on it with a maximum solar PV that generates 40 kWp. It is powered by a system called the "phi-box", which helps the lighting run for 4–5 days on a single solar charge and can provide potable quality drinking water through its inbuilt filter. Such water will be stored inside additional tanks to be used in the toilets. In addition, it is utilized to reduce energy consumption, and therefore electricity bills. Moreover, a smart LED lighting system, incorporating sensors that turn on and turn off lights automatically, will be used [10, 11].

5.3.3 Sustainable Materials

One of the targets of Green Spot is to use the inexpensive and most sustainable recycled materials that are at the same time suitable for the context of Bologna. The main flexible elements are the components of the multi-functional unit's system, made of straw panels [12]. The straw panels are durable, thermal insulated, fire resistant, and have low embodied energy. They can achieve a one-hour fire rating. Over the walls of the kiosks dedicated to the bar and store for products deriving from the activities of cultivation and transformation, green walls will be added to the panels to protect the walls from sun and rain (Fig. 6). For the construction of the bio-lake Miura Board™ sheets, a 100% recycled and sustainable material, will be used (Fig. 7). Miura Board™ sheets are fiber-reinforced composite plastic panels. In the Social Greenhouses, we reused the existing light steel structure to reduce material consumption and the economic and environmental impact.

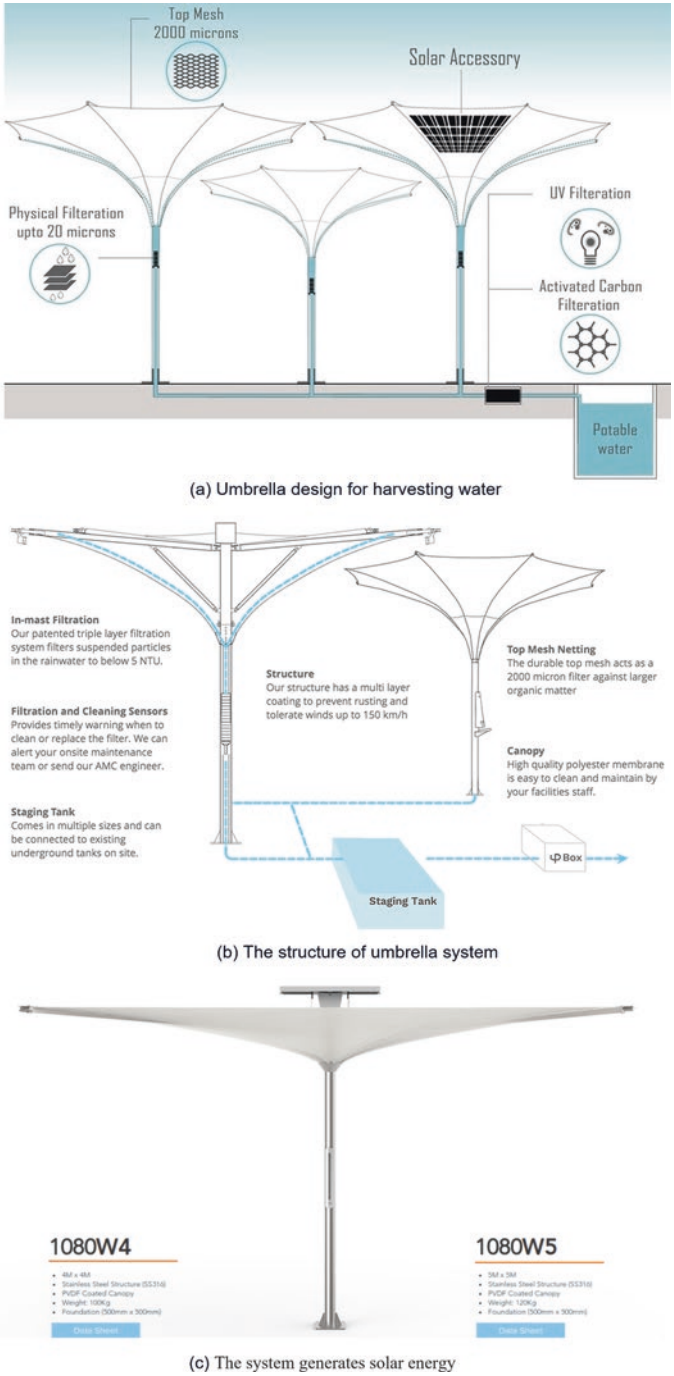

Fig. 5 Structure and functioning of the Inverted Umbrella System. (Image source: FutureEnTech, 2016). (**a**) Umbrella design for harvesting water (**b**) The structure of umbrella system (**c**) The system generates solar energy

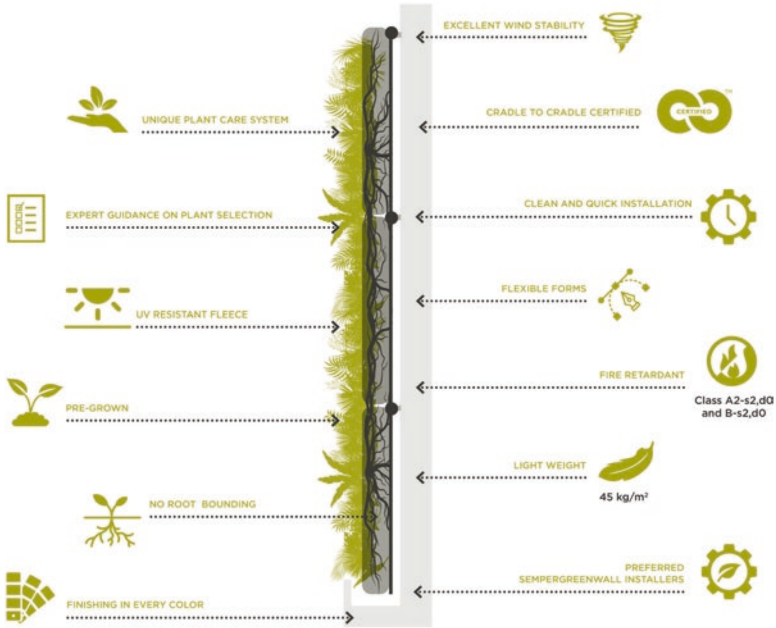

Fig. 6 Characteristics of the green walls. (Image source: Sempergreenwall, 2021)

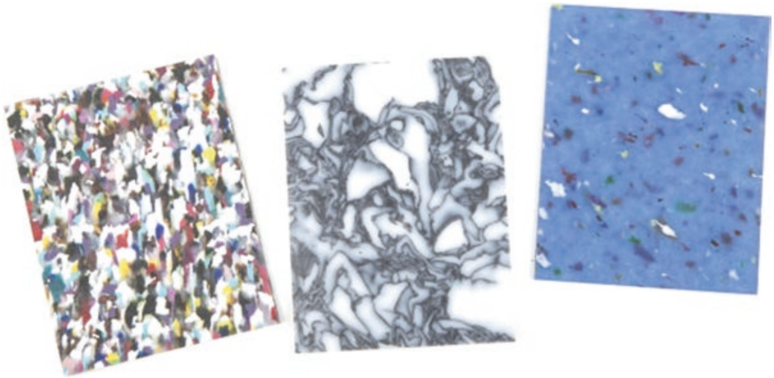

Fig. 7 Types of Miura Board sheets. (Image source Miuraboard, 2021)

5.3.4 Waste Cycle

Green Spot attempts to minimize its impact on the environment; therefore, we plan to reuse as many materials as possible. Thus, the majority of the construction materials will be recycled and/or recyclable. Furthermore, all of the waste coming from the cultivation, and the disposal of all recyclable materials at the end of their cycle will be used to produce compost that acts as the main fertilizer for the plants [13, 14].

5.4 Agriculture Solutions

The study aims to share knowledge about new cultivation systems in the city of Bologna. For this reason, the purpose of the cultivation is to grow safe and healthy vegetables by using an aquaponic system, which is a closed-loop type of agriculture that combines plant cultivation and fish farming.

This method allows for minimizing the usage of external inputs - especially the use of fertilizers since the plants take advantage of the waste that comes from fish farming. Aquaponics combines very well with hydroponics cultivation, for this reason inside the greenhouses, different types of hydroponic systems will be used to grow different plant species. The cultivation will be hosted in the two productive greenhouses which are located near the already existing vegetable garden and it will allow producing fruit vegetables, leafy vegetables, micro-greens, small fruits, and herbs. Despite this, the two productive greenhouses will not be used only to grow vegetables because they will also be a place where people can be involved in the cultivation process and learn new things about a highly efficient and environmentally-friendly growth method.

5.4.1 The Productive Greenhouses

The two productive greenhouses have the same size: they are 127.5 m^2 each. They are East-West oriented and are suitable for cultivation. In the first greenhouse – called *Vertical Cultivation Greenhouse* – the Deep-Water Tower system, patented by Aquaponic Design, will be adopted (Fig. 8). It is a vertical farming system that maximizes production using a small surface. This type of cultivation consists of a modular vertical system suitable to produce leafy vegetables, micro-greens, and

Fig. 8 Deep Water Tower. (Image source: developed by authors)

Fig. 9 Vision of the Vertical Cultivation Greenhouse. (Image source: developed by authors)

small fruits. It also has the advantage of ensuring a water reserve for the plants. To simplify the harvesting process and allow people of different ages to work easily, we considered a height of the tower of 2.00 m which is be able to host 10 holes per column, for a total of 2340 holes in the whole greenhouse as seen in Fig. 9. The main species that will be grown using the Deep-Water Towers system are varieties of lettuce, chicory, rocket, leafy cabbages, basil, parsley, celery, micro greens, and short-cycle herbs like lemon balm, dill, and watercress [15].

The second greenhouse – called *NFT Greenhouse* – as its name suggests, will be based on the use of an innovative Nutrient Film Technique system called the New Growing System (NGS), which facilitates the optimal development of plants. It is made of interconnected layers which create a multi-level circuit to generate small cascades that oxygenate both nutrient solutions and plants Figs. 10 and 11. This type of system is suitable for the cultivation of large crops during summer (like tomato, pepper, and eggplant) and the cultivation of large leaf crops during winter such as cabbages [16].

5.4.2 Seedbed

To have a better planning of the production and also to have availability of new plants to transplant, a seedbed will be placed at the end of the Vertical Cultivation Greenhouse. The plant nursery consists of a rigid grow box with a size of 1.6 × 1.6 × 0.4 m; inside it, there will be a rack structure composed of four layers to ensure optimal germination of the seeds, and the grow box will be equipped

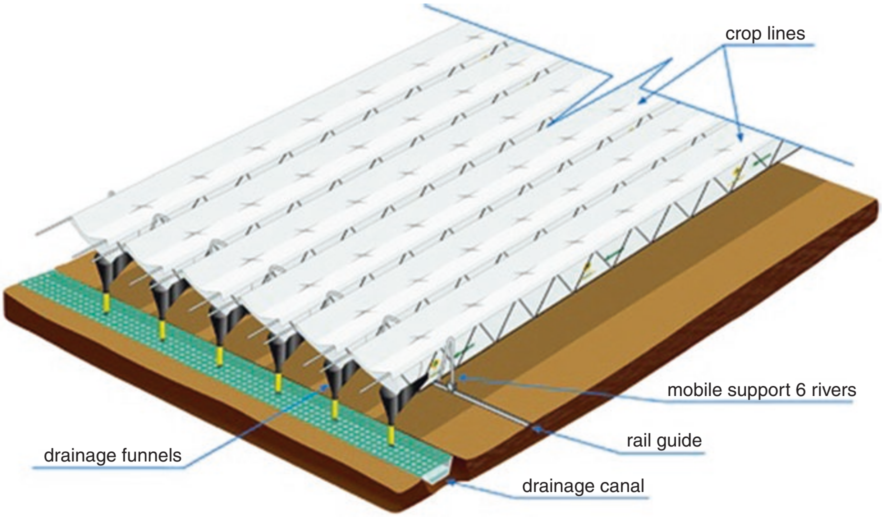

Fig. 10 NGS model of cultivation. (Image source: developed by authors)

Fig. 11 View of the Nutrient Film Technique. (Image source: developed by authors)

with heating coils and vents connected to a thermostat that will modify and stabilize the temperature according to the germination needs. In addition, a red and blue LED lighting system will be placed under each layer of the rack; thus it provides the correct light for fast and balanced growth of the baby plants after germination.

5.4.3 The Bio-Lake

In the space in front of La Serra Madre's entrance, a circular bio-lake will be placed as highlighted in Fig. 12. Its purpose is to collect rainwater through a system of grooves and pipes, mainly from the roofs of the productive and the social greenhouses and from the tent structure that will be constructed above the basin.

The system will also be connected to tanks which will be used to collect further water in case of the necessity of storing water in excess. This project is fundamental from a sustainability point of view since the accumulated moisture will be used to cover all of the water needs of the productive greenhouse.

To use water for irrigation, it will need to be depurated. The cleaning of the water will happen thanks to Phyto depuration, which is a system that exploits the symbiosis between plants and bacteria to purify the water. In particular, the bio-lake will contain water plants, whose roots will release oxygen, which will be then used by aerobic bacteria that naturally develop in such an environment. These bacteria, e.g., *Nitrosomonas* and *Nitrobacter*, will then turn waste materials (for example dead leaves) present in the water first into nitrites, then into nitrates, which will be used by plants as nutrients. Other polluting elements present in the water can be turned by microorganisms into nutrients for plants [17].

Fig. 12 General view of the above-ground bio-lake area. (Image source: Developed by authors)

6 Economical Solutions

Sustainable building innovation creates economic stability, which in turn generates high rates of economic growth and employment. These factors improve project delivery and increase profitability and productivity. One of the project's main goals is to be socially, environmentally and economically sustainable. Hence, analytical information is shown in order to describe the project more clearly from an economic point of view, through the market profile, costs, sources of revenue, and efficiency.

6.1 Market Profile: Activities and Customers

(a) Full sustainability of the services and infrastructures that one attends
(b) Mind and body wellness, favored by contact with nature
(c) Presence of a space that is stimulating and allows us to get to know and put into practice new ways of living

Two main areas of economic activity have been generated. They are called "Creation area" and "Mood area". The Creation area uses raw materials coming from the productive greenhouses and gives them a new value, Mood area benefits from the spaces created inside La Sierra Madre, converting them into a stimulating and interesting area for working, discovering, studying, and many other activities explained afterward. The two areas are specifically articulated as follows:

1. Creation Area:
    - VETRO restaurant
    - Workshop
    - Shop
2. Mood Area:
    - Guided Tours for children
    - Co-working and Co-learning spaces
    - Yoga classes
    - Events, Concerts, and Art Galleries
    - Residencies for artists

6.2 Costs, Sources of Revenue, and Efficiency

6.2.1 Costs and Revenues

Two C4000 systems were chosen for the Nutrient Film Technique (NFT) Greenhouse, while two C8000 systems were selected for the Vertical Cultivation Greenhouse. More specifically, the characteristics and costs for the material and water pumps of the systems are listed in Tables 1 and 2.

Table 1 Costs of items used in the project Green spots

Item	Quantity	Unit cost	Additional costs	Total costs
C 8000	2	13,000 €	–	26,000 €
C 4000	2	6,000 €	–	12,000 €
Seedbed	1	3,400 €	2,000 €	5,400 €
Axial fan	4	500 €	–	2,000 €
Total				**45,400 €**

Table 2 Costs of the Inverted Umbrella systems

Item	Quantity	Unit cost	Total costs
Inverted Umbrella System	6	1,160 €	6,960 €
Strawbale panels	150	600 €	90,000 €
Solar PV panels	14	450 €	6,300 €
Total			**103,260 €**

6.2.2 Main Variable Costs and Sources of Revenue

During the life of the project, the main variable costs that we expect to support are mostly linked to the Purchase of productive factors necessary for cultivation. The main categories include the following main features:

- *Energy for pumps and fans:* the cost will be amortized thanks to the electricity produced by the solar panels.
- *Purchase of seeds and organic sponges:* it will vary depending on the production intensity and the period of the year.
- *Purchase specific types of plants:* to maximize production, we aim to buy grafted plants from external suppliers such as tomatoes, peppers, and eggplants.
- *Labor cost:* also, this voice will vary depending on the productive activity and depending on how many people will attend Le Serre.
- Development and maintenance costs are connected to the website and the Mobile App.

On the other hand, the revenues that we aspect are estimated as follows:

- Restaurant sales
- Shop sales
- Yoga classes participation fees
- Workshops participation fees
- Educational visits for children fees
- Events, Concerts, and Art Galleries tickets
- Le Card subscription

Assuming that the project will start its activities in 2023, the revenues and the employment of personnel are shown in Table 3.

Table 3 Revenues generated and generated jobs in 5 years (2023–2027)

Year	2023	2024	2025	2026	2027
Revenues	1,000,000 €	1,400,000 €	1,900,000 €	2,500,000 €	2,650,000 €
Staff employed	15	16	20	21	21

7 Social Solutions

Since the project is focusing on sharing knowledge about biodiversity, nature cycles, and sustainability with people of different ages through adequate activities and education activities to best suit different users, the social domain are emphasizing on the following issues:

(a) Creating social cohesion between the different age groups.
(b) Creating an interactive environment that fulfills people's needs and encourages them to be influential members of the community.
(c) Creating the next generation of well-educated consumers to ensure conscious food consumption and reduction of food waste.

Part of the planned activities will be oriented towards children of the kindergarten. In fact, involving them in production activities and in workshops will help them to understand the cycles of nature and how vegetables are produced. Another vehicle to facilitate children's interaction with nature will be the playground. Other recipients of the workshops will also be elderly people. The main types of workshops cover issues such as cultivation, biodiversity and waste. *Cultivation workshops* aim to help in understanding how foods are produced and to make clear how much work there is behind the production of the food that they find every day on their tables; *Biodiversity workshops* focus on spreading knowledge about the specific variability of the plants that are present in Le Serre. The biodiversity workshops also address the biodiversity of the herbs cultivated in the aquaponic system and of the plants of the bio-lake, and *Waste workshops* (known as Transformation workshops) concentrate on the transformation processes at no waste and can be applied to the products obtained from the productive greenhouses. All these workshops will be taken in the workshop area inside the social greenhouse [18]. Thanks to the flexible units placed inside the social greenhouse, this space can be lent to various activities. For example, in the morning the mobile units can be moved to create a large space in which it will be possible to take yoga lessons, conferences, book presentations, art exhibitions, or even for evening classes, such as language courses as seen in Fig.13. In addition, artmakers and artisans can rent residences for artists, which are located near the bio-lake, to create their artwork in an environment that enables them to draw inspiration as shown in Fig. 14.

Hence, Le Serre will be more than a simple organization, but a community that gathers people, and gives them a space to satisfy both their social and personal needs. In addition, it allows them to learn how to live a more sustainable lifestyle, in harmony with nature. Therefore, members of the community can have the

Fig. 13 External multifunctional part. (Image source: Developed by authors)

Fig. 14 Vision of the Artists' area. (Image source: Developed by authors)

possibility to pay a yearly membership card for Le Serre, called *'Le Card'*. Such membership gives them the possibility to participate in some events or activities for free or at lower prices. Moreover, Le Card will also be a system to accumulate points. For each activity, people will be involved and allowed to gain points, which can be redeemed for discounts on the participation fees for events or also on the purchase price of fresh and transformed products arising from the aquaponic system that will be sold in the shop.

8 Conclusion

In conclusion, the study and analysis offered a regenerative and livable place for all citizens of the city can people work and enjoy a sustainable environment. Green Spot serves the community by providing a resilient, smart and vibrant place to grow fresh vegetable products and create job opportunities. Also, the methodology proved to be appropriate in achieving the study's set objectives and attaining one more step closer to a more sustainable future and preserving and managing natural resources for the next generations. Moreover, the conservation of biodiversity is the most essential for the upcoming generations. Sustainable development is a theory that states that we should use our resources in such a way that they can also be conserved for our successors. In closing, Green spot not only contributes towards achieving Glasgow Climate Pact 2021 to mitigate GHG emissions and reach net zero by 2050, but also towards climate actions in Italy in general and in Bologna in particular. Furthermore, Green Spot as an innovative, asmart, and asustainable model attains the SDGs, mainly goals 3, 6, 7, 8, 11, 12, 13, 14 and 15.

References

1. Randolph, J., & Masters, G. M. (2018). *Energy for Sustainability Foundations for technology, planning, and policy*. Island Press.
2. Harputlugil, T., & de Wilde, P. (2021). The interaction between humans and buildings for energy efficiency: A critical review. In *Energy research & social science* (Vol. 71, p. 101828). essay, ScienceDirect.
3. Button, R. (2020, February 16). *Old buildings matter: Sustainability and existing structures*. Construction Industry Data. Retrieved August 21, 2022.
4. Richards, M. A. (2018). *Regreening the built environment: Nature, green space, and Sustainability*. Routledge, Taylor & Francis Group.
5. Nandwani, D. (2016). Sustainable urban agriculture: A growing solution to urban food deserts. In *Organic farming for sustainable agriculture* (pp. 325–327). essay, Springer International Publishing. Retrieved August, 2022.
6. Urban farming and Rooftop Gardens. (2015). *The SAGE encyclopaedia of food issues*. https://doi.org/10.4135/9781483346304.n435
7. Katila, P., Pierce, C. C. J., Jong, D. W., Galloway, G., Pacheco, P., & Winkel, G. (2020). *Sustainable development goals: Their impacts on forests and people*. Cambridge University Press.
8. Marco, G. (2019). Manuale Di Aquaponica. Struttura base di un impianto acquaponico, p. 5.
9. Travers, A. A. with J. (2017, May 10). This "inverted umbrella" harvests drinking water and solar energy. *Medium*. Retrieved August 28, 2022, from https://medium.com/invironment/this-inverted-umbrella-harvests-drinking-water-and-solar-energy-a6a63dce1951
10. Correa, C., & Ilse, H. (2001). Energy performance of PV roofs. *Energy and Building, 36*, 763–770.
11. Kala, H. (1985). Wave energy: Cost-effective strategies. *Renewable Energy, 17*(4), 183–188.
12. Layfield, D. (2014). *Durra panel brochure*. Contractors Preparation Guide to Durra Panel, pp. 7–15.
13. Fyvie, E., & Slavin, B. (2018). *The waste cycle: A look at what we use and trash every day*. Kids Can Press.

14. Bruce, S., Weinstien, M., & Lahbhart, J. (n.d.). Turning waste into sustainability. *Waste Cycle*. Retrieved August 28, 2022, from https://www.wastecyclenow.com/
15. Marcelis, L. F. M., & Heuvelink, E. (2019). *Achieving sustainable greenhouse cultivation*. Burleigh Dodds Science Publishing.
16. *NFT system*. NFT System. (n.d.). Retrieved August 21, 2022, from https://www.greenhouse-megastore.com/nft-system
17. *Hydroponic systems: How they work and how to build your own*. Epic Gardening. (2019, December 1). Retrieved August 21, 2022, from https://www.epicgardening.com/hydroponic-systems/
18. Syme, R. (1952). *The near east: Social Aspect*. International Institute of Differing Civilizations.

Co-design Eco-Sustainable and Innovative Retrofit Scenarios in the University Context: The Experience of Bexlab

Antonella Trombadore, Lucia Montoni, Giacomo Pierucci, and Gisella Calcagno

1 Introduction

Mediterranean countries are strongly characterized by the availability of an existing building stock that just in a few cases respect the current energy regulation. The Renovation Wave initiative [1], into the framework of the ambitious Green Deal for a zero climate impact by 2050, underlines the necessity of existing buildings' renovation in terms not only of energy efficiency but also human comfort and well-being. Considering that a large part of the existing heritage has an historical and architectural value, the challenge lies in combining contemporary needs and building performance requirements with the constraints of historical architecture.

As reported in the 2030 Agenda for Sustainable Development, one of the ambitious and transformational visions looks at "A world where human habitats are safe, resilient and sustainable and where there is universal access to affordable, reliable and sustainable energy" [2].

The emerging need to consider building renovations lies in the positive impact they can bring to society: energy and environmental benefits, such as reduced energy poverty, the worst-performing buildings, and greenhouse gas emissions, but also health improvements (better air quality and indoor comfort), jobs creation and financial savings [3].

A further step is the recognition by citizens of these issues as a priority for their lives on the Planet. In the construction of human awareness, education has a fundamental role towards the adoption of conscious, responsible, and proactive behaviors in terms of implementing real change for a sustainable future.

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The role of education in global development must be rethought, as well as the ways to transmit eco-sustainability issues, such as climate change, biodiversity, disaster risk reduction, water, the oceans, and sustainable urbanization and lifestyles [4]. The Education for Sustainable Development for 2030 (ESD) programme [5], promoted by UNESCO, and the New European Bauhaus initiative [6], which was launched in 2020 by the EU Commission, promote new activities and approaches to involve users in the individual and societal transformation necessary to change course.

Addressing these international sustainable challenges to drastically reduce the environmental impacts and introduce educational activities for society, the experimentation of collaborative and participative approaches in the necessary renovation process of the public built heritage is an interesting challenge today in the Mediterranean area. The paper looks at universities as a great opportunity to deal with the need for innovative, creative and eco-sustainable solutions for the retrofit of existing buildings, and the application of methodologies for the engagement of students, both as final users of the retrofitted spaces and future generations of designers. As an example of this approach, the beX Living Lab settled in the School of Architecture of the University of Florence, organized a co-design workshop to re-think the envelope of the existing university building for better energy performances and well-being in indoor spaces.

2 Empowering the Role of University

Universities are a fundamental part of the community as places of research and innovation and as educators of the future generation of citizens, but also professionals and decision-makers. Both didactical and innovative roles enable the university as the ideal place for the experimentation of best sustainable practices. Approaching co-production of knowledge in the renovation processes, ambitious energy and environmental quality targets could be reached through the activation of innovative strategies and activities, such as seminars, workshops, and engaging students and stakeholders involved in the renovation process.

As NEB underlines, there is a growing interest in the integration of culture in the process of making our society more sustainable and inclusive. Promoting the learning and idea-sharing on climate-friendly architecture and participative co-design processes helps to open a dialogue between the different stakeholders involved (as planners, managers, and final users) and create a user-centered research and innovation led by final users.

In line with this idea, the Living Labs methodology can provide new perspectives in the passage from user-centered to participatory design [7, 8]. ENoLL (European Networks of Living Labs) defines LLs as 'open innovation ecosystems in real-life environments using iterative feedback processes throughout a lifecycle approach of an innovation to create sustainable impact' (https://enoll.org/about-us/). Two important aspects characterize the LL approach: the first concerns the innovation process between users, user community and public and private firms in real-life environments; the second regards the co-creation process that allows to build up the necessary knowledge for the environmental awareness, from the conception to the realization of the project. The engagement of users in the experience of alternatives, the co-creation of new scenarios for a more sustainable lifestyle, and the co-design of pilot buildings and spaces can encourage the transformation of values, principles, and behaviors of the community [9].

Inside the Med-EcoSuRe project, founded by the European Union Program ENI CBC MED, the beX (building environmental eXperience) Living Lab was settled within the School of Architecture of the University of Florence as a strategic setting delivering research, teaching, and social responsibility goals [10]. The Lab faces the need of rethinking the built heritage in terms of Energy Efficiency by connecting interdisciplinary competencies to valorize the environmental experience in transformations and renovations. Placed inside the university building, it is a space set up for the co-creation and experimentation of emerging ideas on environmental topics, implementing different scenarios and innovative concepts. Since the building sector is among the largest energy consumers with a high impact on the ecosystem, encouraging students to explore through themselves the perception of well-being in buildings is very important to find new solutions to the current effects of climate change, of the current energy crisis and to face the new "green" challenges [11, 12].

3 Sensible Skin for Santa Verdiana: An Interdisciplinary Workshop with Students

3.1 Framework of the Workshop

The interdisciplinary research group of the beXLab, according to the LLs model, launched a training workshop and a design competition for architectural students for the co-design of a new 'Sensible Skin for Santa Verdiana'. The case study, placed within the School of Architecture of the University of Florence, in the historical complex of Santa Verdiana, includes three rooms situated in two levels with two open façades and the beXLab placed on the ground floor. Thanks to the dynamic monitoring system (sensors, IoT) already installed in the room of the beXLab, it is possible to observe, evaluate and quantify the indoor environmental quality.

The activity focused on the development of an innovative and eco-sustainable mix of technologies for the envelope of the pilot building, especially for the southern façade that presents the main criticalities. The workshop had the objective of stimulating creative thinking on energy performances and human comfort and well-being, and at the same time, raising students' awareness on sustainability and energy behaviors. Based on the implementation and valorization of the environmental interrelated aspects in buildings, the activity wanted to offer students the opportunity to face a real energy retrofitting process inside a well-known place.

Unlike frontal lectures, the competition of ideas is a tool that encourages the engagement of the general public and, in this case, invites university students to present innovative and eco-sustainable proposals. After the submission, ideas were commented, discussed, and voted on by a selected jury which includes, in addition to the academic staff, the plurality of stakeholders involved in the innovation process of building renovation: the Technical Office of the University (manager of the building), the Municipality of Florence (owner of the property) and the Superintendence of Archeology, Fine Arts and Landscape for the metropolitan city of Florence and Prato, as the responsibility for protecting the architectural heritage.

3.2 Methodology

The activity was divided into three main phases:

1. Introduction
2. Exploration and Experimentation
3. Evaluation of Scenarios

The first step has been focused on training sessions about the pilot building's knowledge and the analysis of criticalities: students were introduced to the architectural and historical study, the functional and environmental requirements, and the understanding of different users (stakeholders) involved in the entire retrofit process of the building (Fig. 1), as well as sharing best practices of traditional and innovative retrofit strategies and technologies in the Mediterranean context.

The complexity of the project for Santa Verdiana refers to the combining of internal comfort needs and good energy performance with architectural quality since the building presents architectural constraints, production of renewable energy and social values related to an intervention in the core of the historical University. Academics and experts from different disciplines related to retrofit processes were involved to transmit this complexity and to underline the need for an interdisciplinary approach to students.

Systematizing and organizing the previous information collected, the second phase of the workshop was related to the development of creative thinking on energy and environmental solutions of the existing building in view of a retrofit project.

Students were divided into small working groups in order to explore and discuss together different design solutions and experiment with the use of materials, technologies, and shapes, integrating new functions useful to university users (Fig. 2).

The solutions proposed in this phase regard different levels of design hypotheses, from technological details to overall solutions that consider general aspects of the context.

Working with digital technologies facilitated the transition from experimentation to evaluation. Students had the possibility to interact with the digital technologies available in the Lab (BIM, IoT, Digital Twin) from the earliest design stages,

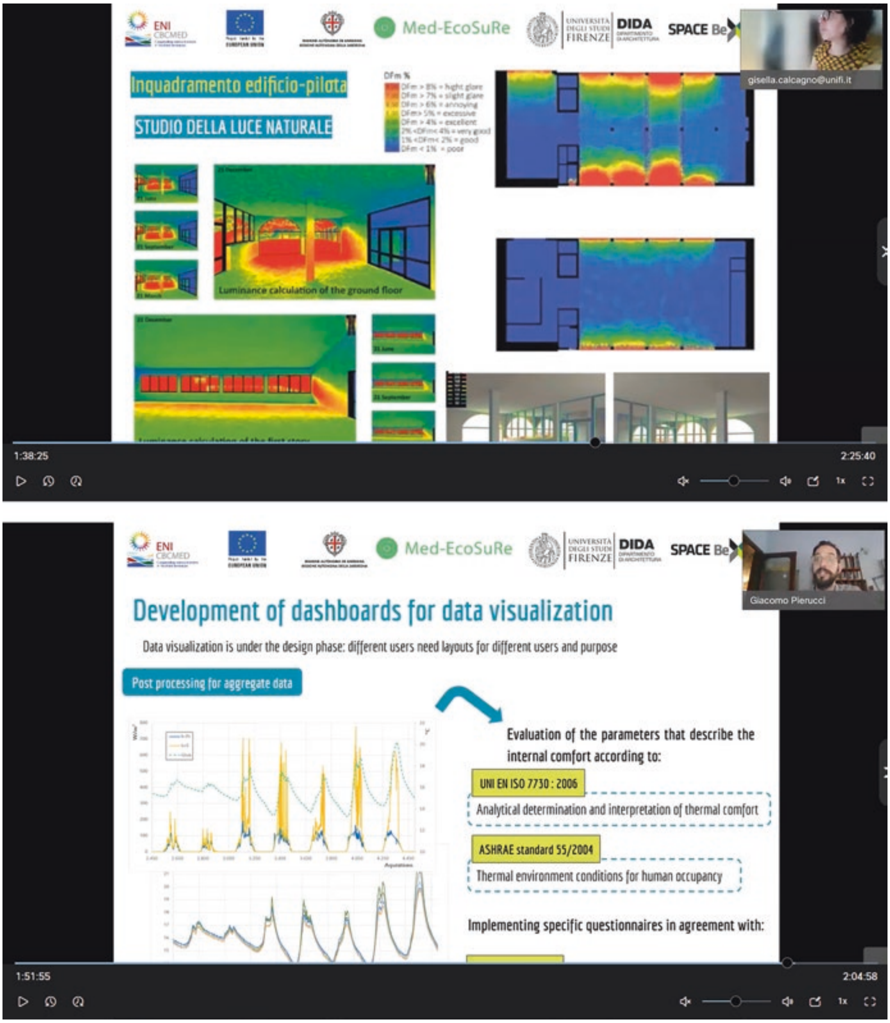

Fig. 1 Transmission of the framework knowledge and digital technology tools

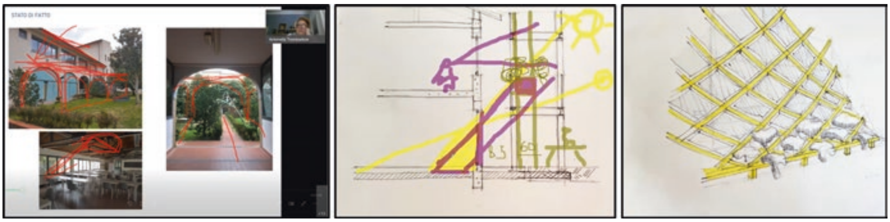

Fig. 2 Screenshots from collective virtual brainstorming and co-creation strategies for the generation of creative ideas

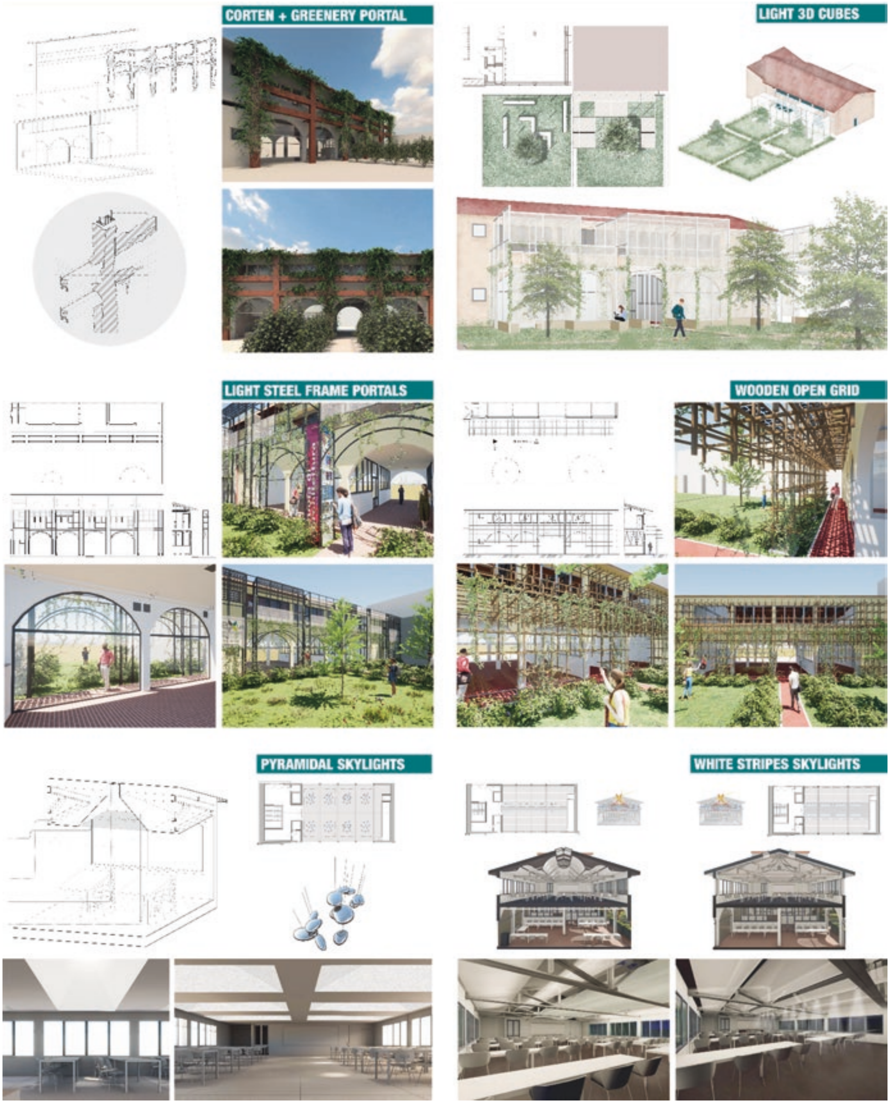

Fig. 3 Some selected works of the competition made by students

enabling people to understand and predict the energy and environmental performance of the building but also to define improvement scenarios of intervention.

The third and final step concerned the verification of the best solutions proposed by each group (Fig. 3): the assessment was based on the requirements and criticalities defined before and on the possibility of producing other (and new) positive sustainable impacts in the general context.

Considering the individualized energy and environmental criticalities, but also the architectural constraints, students were driven towards the realization of an external three-dimensional structure. The option of a structure detached from the building allows greater design freedom since integration in the historical context requires particular attention to the reversibility and feasibility of the intervention.

All façade solutions have in common certain features, such as the integration of photovoltaic panels for renewable energy production, elements for improving summer thermo-hygrometric conditions and internal natural lighting, and modularity, which ensures ease of transport, assembly and disassembly – a very important aspect in a historical building context.

Figure 3 shows some of the students' work presented: some projects included the integration of greenery, such as vertical greening or gardens, as an element of solar shading and at the same time to improve air quality. In other cases, the project focuses on the use of natural materials and low-impact technologies, as in the case of the interlocking wooden structure, or the search for recycled materials such as recycled viscose textile produced at the local level. Some of these solutions, closer to the idea of temporary installation, are distinguished by their lightness and reversibility; the self-supporting steel structure allows for the testing over time of different materials and technologies in horizontal, vertical and sloping surfaces; the solution with fabric, on the other hand, extends the sun-shading elements to part of the courtyard, creating new spaces for the enjoyment of the garden.

4 Conclusion

The co-design experience of the beXLab took part in the partnership of the University of Florence with the New European Bauhaus initiative. Interdisciplinary and collective workshops, organized at the University of Florence, aimed to start a co-planning process with students and PhD candidates towards the sharing and the appropriation of NEB's principles. These activities became creative contexts of relationships and exchanges in which to share the vision of the future in order to design the contemporary, starting from the students' vision. Active participation in participative co-design experience is a key element in this process of engaging users and stimulating change. Due to the restrictions of COVID-19, the workshop organized by beXLab was held entirely online, and the distance did not facilitate some of the dynamics between the working groups and the possibility ofdirectly interacting with the analyzed spaces.

Moreover, the involvement of students in the project for Santa Verdiana does not end with the co-design phase, because as end users of the regenerated spaces, are the community that will actively live the spaces and will perceive the new comfort and well-being with awareness of the process behind it.

After the realization of the structure, students will provide a real perception of comfort and well-being. In conclusion, thanks to participative activities organized inside schools and universities, students can finally experience specific knowledge on the existing building energy and environmental analysis, design and assessment, and the identification of the stakeholders involved in these interventions.

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References

1. European Commission. (2020). *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757 & uri=CELEX:52020DC0662
2. United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. Available at: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf. Accessed in Aug 2022.
3. Nina, M., Launonen, P., & Oliveira, Á. D. (2014). APOLLON - using living lab methodologies in the cross-border context for energy efficiency pilots. In M. Helfert, K. H. Krempels, & B. Donellan (Eds.), *3rd international conference on smart grids and green IT systems (Smartgreens 2014), Barcelona, Spain, 3–4 April 2014* (pp. 336–342).
4. Longoria, L., López-Forniés, I., Sáenz, D., & Sierra-Pérez, J. (2021). Promoting sustainable consumption in Higher Education Institutions through integrative co-creative processes involving relevant stakeholders. *Sustainable Production and Consumption, 28*, 445–458.
5. UNESCO. (2020). *Education for sustainable development*. Available online at: https://unesdoc.unesco.org/ark:/48223/pf0000374802
6. European Commission. (2020). *New European Bauhaus*. Available online at https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_4627
7. Dell'Era, C., & Landoni, P. (2014). Living lab: A methodology between user-centred design and participatory design. *Creativity and Information Management, 23*(2), 137–154. https://doi.org/10.1111/caim.12061
8. Hossain, M., Leminen, S., & Westerlund, M. (2019). A systematic review of living lab literature. *TECHNE - Journal of Cleaner Production, 213*, 976–988.
9. Masseck, T. (2014). Living labs in architecture: Open innovation and co-creation towards a more sustainable architecture and lifestyle. In *WSB 14 conference proceedings*. World sustainable building conference, Barcelona. https://upcommons.upc.edu/handle/2117/26119
10. Trombadore, A., & Calcagno, G. (2022). Mediterranean university as catalyst for eco-sustainable renovation: The experience of med-EcoSuRe cross-border living lab. In A. Sayigh (Ed.), *Sustainable energy development and innovation. Innovative renewable energy*. Springer. https://doi.org/10.1007/978-3-030-76221-6_34
11. Evans, J., Jones, R., Karvonen, A., Millard, L., & Wendler, J. (2015). Living labs and co-production: University campuses as platforms for sustainability science. *Current Opinion in Environmental Sustainability, 16*, 1–6.
12. Zaballos, A., Briones, A., Massa, A., Centelles, P., & Caballero, V. (2020). A smart campus' digital twin for sustainable comfort monitoring. *Sustainability, 12*(21), 9196.

Building Digital Scenarios to Predict Energy-Efficient Renovations: The Experience of beXLab

Gisella Calcagno, Lucia Montoni, Juan Camilo Olano, and Giacomo Pierucci

1 Dealing with the Renovation Wave

In the European Union, buildings are the largest energy consumers, responsible for approximately 40% of energy use and 36% of energy-related greenhouse gas emissions. Notwithstanding the 20 years-old Energy Performance Building Directive (EPBD 2002, recast 2010 and amendment 2018), nowadays around 75% of the EU building stock is inefficient with low renovation rates [1]. Looking at the evolution of the EPBD, it is possible to note progressive attention on the rehabilitation of the existing buildings, with even deeper renovations required to reach the Nearly Zero-energy building target, referring to building with nearly zero or very low amount of energy required covered to a very significant extent by energy from renewable sources.

In more recent years, in the context of the ambitious European Green Deal aiming to cut 55% of greenhouse emissions in the EU by 2030 and to reach climate neutrality by 2050, the EU Commission launched the Renovation Wave strategy, which is requiring an anticipated revision of the EPBD to set out how to achieve a zero-emission and fully decarbonized building stock by 2050. The guiding principles for building renovation proposed by the strategy are based on the commitment "energy efficiency first", and address the objectives of decarbonization and integration of renewables, life-cycle thinking and circularity, high health and environmental standards, also considering architectural quality and aesthetics. Moreover, the

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strategy expresses the need, and opportunity, to tackle together the twin challenges of the green and digital transition, to promote digitally friendly renovations [2].

The EU approach to building renovations underlines the possibility of taking the maximum contribution of energy rehabilitations, not only in terms of energy savings and environmental impacts (reduction of energy consumption and greenhouse emissions), but also considering the wider benefits related to health and comfort for occupants, highly influencing the quality of living. Besides, this topic of quality living spaces in terms of sustainable lifestyles but also aesthetics and inclusion has been re-valued by the EU Commission's initiative New European Bauhaus, promoting creativity and transdisciplinarity [3].

Occurring in the lifecycle of an existing building, the renovation process is based on the acknowledgement of the actual energy performances in order to define improvement scenarios. All existing buildings have a potential for renovation: discovering and exploiting it is the objective of the renovation design project that, starting from the existing, has to envision integrated scenarios of energy efficiency, eco-compatibility, architectural quality and comfort and well-being for occupants. In the run towards renovation, digital technologies can play an enabling role to support more reliable and ambitious design processes, consenting to take into account integrated objectives starting from energy efficiency.

2 The Enabling Role of Digital Technologies

The key principle of twinning the green and digital transitions in the Renovation Wave refers to the EU priority of digitalization, with the strategy "A Europe fit for the digital age" fostering the empowering role of digital technologies for a human-centered, sustainable and prosperous future.

Given the complex and lasting nature of building processes, digitalization is considered a game changer, since digital technologies (intended as electronic tools, systems, devices and resources to generate store or process data) can improve the productivity of both the Architecture, Engineering and Construction industry, and the Operation and Facilities Management sector. In fact, as recognized by the EU Commission, the under-digitalization of the building sector determines low levels of collaboration and poor management of information, originating a chain of problems affecting the unpredictability of costs and times [4].

This is particularly relevant in building renovation processes, in which the combination of interrelated aspects (building, energy, human), and a correct information flow among a range of specialists (energy managers, engineers, architects) and also end-users are fundamental to ensure successful outcomes. For these reasons, digital technologies are crucial to accelerate the Renovation Wave, not only to give centrality to energy performance but to fully acknowledge the multiple benefits of building renovations.

Looking at digital technologies, BIM (Building Information Modelling) is increasingly recognized as the most promising for the building sector, allowing the creation of a data-rich, interoperable and implementable digital model of the building to evaluate, in an integrated way, the impact of each decision. It is the life-cycle perspective that can explain the success of the BIM methodology, with the possibility to drive the building from the design phase to operation and management. For this feature, BIM is even more considered in the field of building retrofit, where the construction of a digital model of the existing can boost the reliability of the whole renovation process.

The growing digital possibilities to collect, analyze, visualize and interact with an even larger amount of objective and subjective data represent an enabling potential for the renovation of the built environment, consenting to better acknowledge the state of art and to foreseen future improvement scenarios, starting from energy efficiency. However, the adoption of digital technologies requires a deep cultural change towards digital thinking rather than the introduction of new software, with the creation of value not immediate but achievable in the long-term. Notwithstanding the different EU initiatives on BIM, nowadays the only reference is the Public Procurement Directive 2014, followed in the last years by the definition of an EU Framework for Buildings Digital Logbook [5].

In the meantime, the full exploitation of BIM has just begun to be discovered: its interoperability is in fact the basis to match with other emerging digital technologies, such as robotics, drones, 3D printing and scanning, sensors and IoTs. In this innovation path, the most advanced concept is the Digital Twin, a virtual replica dynamically connected with the real building thanks to the integration of BIM with sensors, IOTs and machine learning, consenting to envision “cognitive buildings” that automatically determine their functioning by learning from themselves [6].

3 Between the Existing and the Renewed: Building Digital Scenarios

From a practical point of view, the financial investment in energy renovations is activated when the cost of the intervention can be amortized in a proper span of time by the reduction of energy consumption. For this reason, the calculation of energy savings is central in the renovation process, requiring the assessment of the energy performances of the existing building and the comparison with the ones achievable in the future configurations. According to EPBD, building energy performances are based on the evaluation of the building/plant system, referring to quantitative parameters mainly related to the performances of the envelope (e.g. thermal transmittance) and efficiency of the different energy supply systems (heating, cooling, ventilation, lighting and domestic hot water). Focusing on numbers, this approach impedes taking into account, and valorizing, the contribution of other interrelated aspects, such as users’ comfort and well-being, low environmental impact, and architectural quality.

The need to look beyond energy efficiency suggested by the EU directions can be addressed in the design phase, the heart of the renovation process, when the constraints of the existing building can become opportunities in integrated architectural solutions, exploiting the design culture and creativity to guide the definition of the best renovation scenario.

The proposed methodology aims at discovering the renovation potential of the existing building in order to design integrated scenarios merging four interrelated objectives of energy efficiency, comfort and well-being, architectural quality and low environmental impact.

Dedicated to the first phases of the design process, the methodology helps the definition of the best mix of technologies by exploiting the BIM model to jointly perform energy and environmental simulations, while considering the architectural aspects related to the integration of new technologies. Usually, the simulations of building energy performance are relegated to the late phases of the design process and conducted by specialists for the verification of the preliminary design; instead, they can be anticipated in the first phases of the design process when modifications are highly impacting [7–9].

Based on the standard and minimum data set, the creation of a BIM asset model of the existing building is the precondition for the definition of a reliable knowledge framework, harmonizing various data and information from previous documents and surveys. The interoperable model allows to perform preliminary simulations of the energy and environmental performance of the existing building and to visualize its main criticalities. The analysis of criticalities consents to a building-specific calibration of the renovation objectives, with the definition of Key Performance Indicators.

Since the early stages of the renovation design process, the BIM asset model, synchronized with performance simulations tools, can act interactively and iteratively as a benchmark to evaluate the improvements deriving from the integration of a single/set of renovation technologies in x scenarios, to be assessed on the basis of KPI.

Beyond the BIM-enabled possibility to optimize the pre-design thanks to the interoperability with performance simulation tools, working around a single-shared BIM model fosters the collaboration between designers and specialists, as well as the communication with non-experts, such as owners and end-users, supporting co-design processes.

4 The Case Study

The methodology was tested in the design phase of the energy renovation pilot action foreseen by the international project Med-EcoSuRe (financed by the ENI CBC Med programme 2016–2020), aiming at fostering the role of universities as catalyst for an innovative and eco-sustainable renovation of public buildings in the Mediterranean area [10].

In the context of the pilot-university building to renovate, a Living Lab (beX-Lab – building environmental eXperience) has been set up as an intermediate entity to stimulate the collaboration among stakeholders (university decision-makers, building and energy managers, but also innovative local companies and experts) and to take into account, valorize the role of users in the energy renovation process, by experimenting with the advancements of digital technologies [11]. The experimentation in the Living Lab looks at the definition of fully implemented Digital Twins, bi-directionally connecting the physical building with a digital model with the aim to support the information exchange and evidence-based decision-making across all the phases of the renovation process (knowledge framework, analysis of criticalities, planning and design, intervention, post-management).

The interdisciplinary research group is exploiting the BIM methodology as the best path for an innovative and eco-sustainable renovation process, as well as for the creation of the digital side of the Digital Twin, matched with the physical pilot-building through an installed monitoring system, continuously collecting data on environmental factors influencing human comfort (e.g., temperature, humidity, illuminance, and CO_2 levels).

4.1 Knowledge Framework

For the energy renovation pilot project, a building block was selected in the School of Architecture of the University of Florence, hosting typical functions of the university life (didactics, study and research laboratory) (Fig. 1). The main peculiarity of the pilot site is the position in the historical complex of Santa Verdiana, in the UNESCO city center of Florence (Italy), dating back to the late XIV century, created as a convent, transformed over centuries into a female prison, to finally host the educational function in the 80's, construction period of the pilot-building.

For the definition of the knowledge framework, a BIM model has been populated with different typologies of data (such as building geometry, envelope stratigraphies and technical system) coming from different sources (existing drawings, technical sheets, field surveys, previous documents).

Fig. 1 South façade of the pilot building under renovation in the School of Architecture – Santa Verdiana, Florence and the digital BIM model

With a total surface of 412 m^2, the two floors building block is characterized by a symmetrical but opposite north-south exposition. The envelope is composed of opaque vertical walls in tuff finished with plaster; transparent elements are characterized by a single glass layer on the ground floor, where they are prominent in fixed archways, and double glasses in the windows of the first floor; the roof is made by prefabricated sandwich panels covered by a mantle of traditional clay tiles. The functioning of the building is guaranteed by the presence of a heat pump powering heating and cooling with a standard ventilation system; it is not foreseen hot domestic water; and the artificial lighting is provided by old neon lamps.

4.2 Analysis of Criticalities and Definition of Renovation KPI

Equipped with these data and information, the BIM asset model has been exported to simulate the energy and environmental performance of the building with the Sefaira application (by Trimble), working with dynamic calculation algorithms (hourly steps) and specifically dedicated to the first phases of the design process, not requiring detailed initial data.

Simulations show the low energy performances of the pilot building with major consumptions referable to air conditioning and artificial light, in line with the previous energy audit. It is suitable to consider the results more in a relative than in an absolute sense: at this step, even if the simulation should not be deeply accurate due to some limits about the boundary conditions hypothesis, it consents to acknowledge the most impacting phenomena in a global balance and the relationships among them.

Focusing on the thermal behavior of the building, the simulation consents to calculate the impact of the passive thermal contributions of the envelope on energy consumptions for heating and cooling, showing that the most impacting negative contribution, more than the double of the others, regards solar radiation on the south façade (Fig. 2 left).

Given the destination use, a big attention is given to the quality of the visual environment, with simulations on the distribution and intensity of solar radiation inside the spaces (daylight factor and illuminance). The analysis reveals the uneven distribution of natural light, with the overexposure to solar radiation from south in particular in the ground floor, due to the dimension of the windows, and with underlit in the central part of the first floor (Fig. 2, right).

Looking at the building criticalities through the lens of the four interrelated renovation objectives, it was possible to identify the Key Performance Indicators to assess the best renovation scenario for the pilot building (Fig. 3):

1. Energy Efficiency
   1.1. Reduction of energy consumption for lighting
   1.2. Reduction of energy consumption for cooling

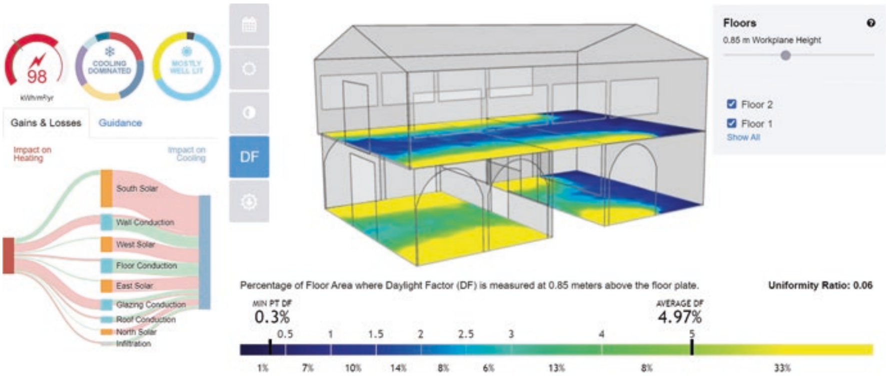

Fig. 2 Passive thermal energy through the building envelope and impact on heating and cooling (left) – Daylight factor analysis (right) before renovation

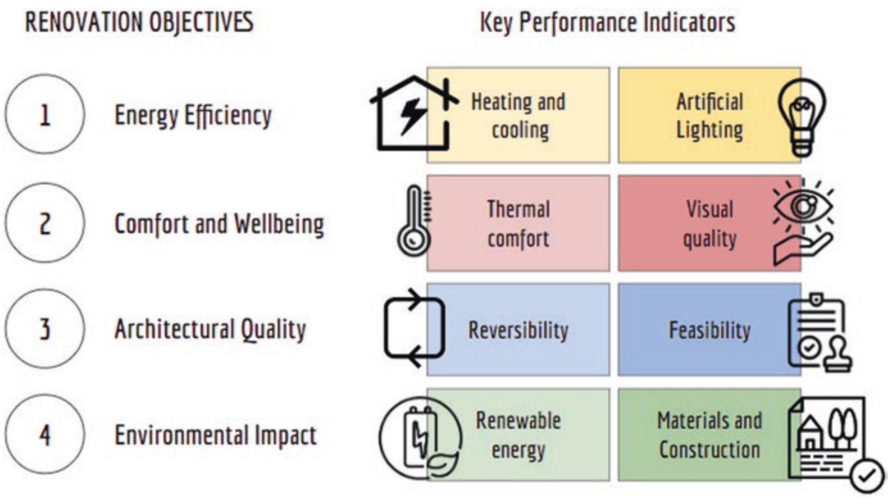

Fig. 3 Framework of renovation objectives and building-specific Key Performance Indicators

2. Comfort and well-being
    2.1. Improvement of visual comfort
    2.2. Improvement of thermal comfort, in particular in the summer period
3. Architectural quality
    3.1. Feasibility: due to the position, the building renovation is subject to restrictions by the Cultural Heritage Agency, requiring to consider the integration into the architectural heritage;
    3.2. Reversibility: due to the architectural constraint, the building intervention has to be fully reversible without compromising the architectural heritage

4. Environmental impact
    4.1. Clean energy production from renewable sources
    4.2. Low environmental impact of materials and construction systems

4.3 Building Renovation Scenarios

As a pre-design phase, the definition of renovation scenarios has the objective to find the most coherent and efficient mix of technologies to solve the criticalities of the existing building. By exploiting the BIM asset model, different architectural scenarios have been designed to address in an integrated way the retrofit objectives, to be assessed on the basis of the defined KPI.

To guide the selection of the most appropriate mix of technologies, renovation strategies have been adopted based on the Mediterranean bioclimatic architectural tradition, but also exploiting the potential of solar energy, resulting in both passive and active technologies:

- Valorizing daylight (e.g., solar shelves, solar pipes, windows, skylights, selective glasses)
- Favoring natural ventilation (e.g., windows, skylights)
- Modulating solar radiation (e.g., solar shading systems)
- Integrating green elements (e.g., green façade, green roof)
- Integrating renewable energy systems (e.g., photovoltaic panels)

Considering the binding requirements to intervene in the historical context and related to the objective of architectural quality, three macro-scenarios have been defined according to the degree of integration of the renovation technologies to the existing building (Fig. 4):

1. Envelope: direct intervention on the opaque and transparent envelope through the substitution/addiction of technical elements
2. Double-skin: addiction to technological solutions detached but integrated into the envelope of the existing building
3. 3D structure: positioning of an independent external tridimensional structure in the space around the building

Fig. 4 Architectural macro-scenario to search the best renovation scenario

According to each macro-scenario, different technologies have been integrated and tested on the digital BIM model to simulate the improvement of energy and environmental performance, compared between them and with the performance of the existing building. It was possible to observe the contribution of the single technologies to the achievement of the KPI, but also the contribution deriving from their integration. For example, the need to protect the south front from the impacting solar radiation has been evaluated with different shading devices, also with the integration of photovoltaic systems.

4.4 Best Renovation Scenario

Guided by the definition of macro-scenarios, the analysis of the different renovation technologies and their integration consented to define the most optimal mix of technologies for the energy rehabilitation of the pilot-building. Addressing in an integrated way the renovation objectives and satisfying the defined KPI, the pilot project foreseen two main interventions related to two macro scenarios: the addition of an external 3D structure and the opening of skylights in the roof. Although direct intervention on the envelope would have guaranteed the achievement of higher levels of indoor comfort and energy efficiency, the need to consider architectural quality in the historical context required to limit irreversible interventions on the main façades (i.e. exterior insulation and finishing system).

Detached 1.5 mt from the south façade, the tridimensional steel dry structure is self-supporting and hosts 120 photovoltaic panels (30 × 200 cm of exposed surface each) in two levels, intended both to produce renewable energy and to shade the first and the ground floors. PV panels are in amorphous silicon, whose semi-transparence augments the integrability in the protected context; moreover, other PV panels are placed at the top of the 3D structure to increase the energy production, for a total of 5–6 Kwp. The 3D structure consents to reach the fourth interrelated renovation objectives and to address the specific KPI of passive improvement of thermal comfort in the summer period, reduction of energy consumptions for cooling, reversibility and production of energy from renewable sources (Fig. 5).

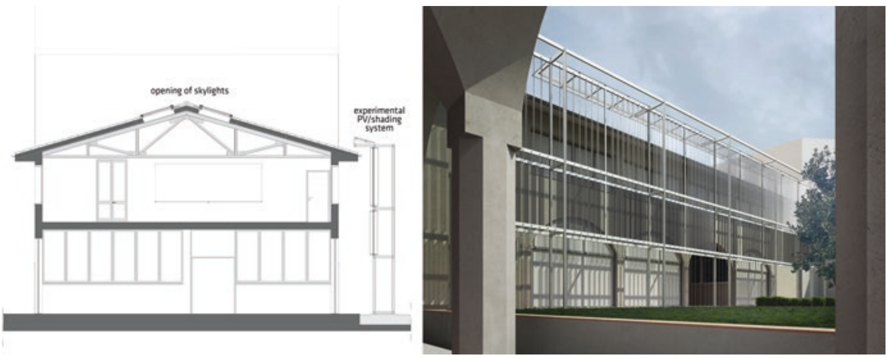

Fig. 5 3D steel structure in front of the south façade with PV Solar Shading

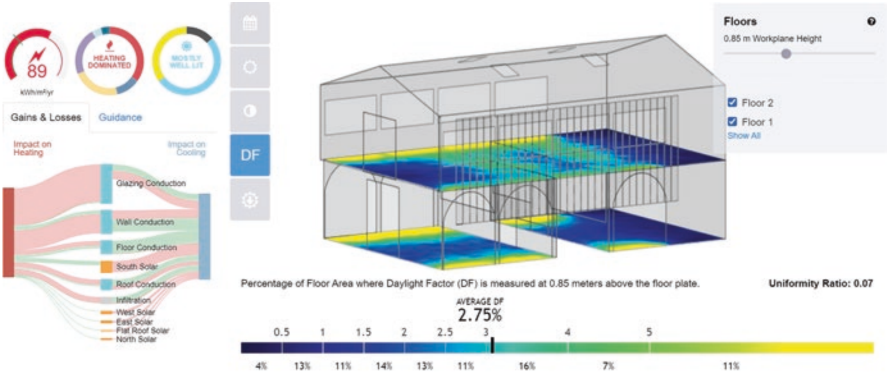

Fig. 6 Passive thermal energy through the building envelope and impact on heating and cooling (left) – Daylight factor analysis (right) of the renovation project

The second intervention regards the realization of skylights in the central part of the roof covering the aula magna on the underlit first floor; the entering of daylight improves visual comfort, reduces energy consumption for lighting throughout the year and contributes to natural ventilation. The renovation project consents to reaches better energy performance and daylight contributions (Fig. 6).

5 Conclusion and Future Works

The energy renovation of existing buildings is central to the EU commitment to contrast climate change, but also to approach the ongoing energy crisis. Beyond energy efficiency, energy renovations can be more ambitious considering the improvement of indoor comfort and well-being for occupants, architectural quality and low environmental impact, with an integrated project required to achieve the interrelated objectives.

The advancements in digital technologies are increasingly recognized as supportive of more efficient and reliable building processes, starting from an improved design phase. In the case of energy renovations, the more stimulating digital opportunity is the life-cycle perspective of the BIM, giving the possibility to acknowledge the current state of the building, recognize its criticalities, and continuously enrich the model towards the design of improvement scenarios and future management.

The definition of a stable and trustable knowledge framework of the existing building through a standardized BIM asset model represents the precondition for a successful renovation project, harmonizing and collecting in a single model a wide range of data and information coming from different sources. The BIM interoperability with performance simulation tools allows a preliminary analysis of the criticalities of the existing building, consenting to define building-specific Key Performance Indicators to guide the definition of improvement scenarios.

Supported by simulations, the BIM asset model acts as a benchmark for the experimentation of renovation scenarios, based on mix-of-technologies addressing the existing criticalities, for the selection of the best scenario achieving, in an integrated way, ambitious renovation objectives. The further evolution of BIM towards Digital Twin under experimentation will allow a full validation of the performed simulations, augmenting the reliability of the digital model thanks to real dynamic information from monitoring systems and IoT technologies.

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References

1. European Commission. (2021). *Impact assessment report accompanying the Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast).* Available online at https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX:52021SC0453
2. European Commission. (2020). *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662
3. European Commission. (2020). *New European Bauhaus*. Available online at https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_4627
4. European Commission. (2019). *Supporting digitalisation of the construction sector and SMEs Including Building Information Modelling.* Available online at https://op.europa.eu/en/publication-detail/-/publication/09766efa-0188-11ed-acce-01aa75ed71a1/language-en
5. European Commission. (2020). *Definition of the digital building logbook.* Available online at https://op.europa.eu/it/publication-detail/-/publication/cacf9ee6-06ba-11eb-a511-01aa75ed71a1/language-en
6. Khajavi, S., Motlagh, N., Jaribion, A., Werner, L., & Holmstrom, J. (2019). Digital twin: Vision, benefits, boundaries, and creation for buildings. *IEEE Access, 7*, 147406–147419.
7. Elnabawi, M. H. (2020). Building information modelling-based building energy modelling: Investigation of interoperability and simulation results. *Frontiers in Built Environment, 6*, 573971.
8. Bonomolo, M., Di Lisi, S., & Leone, G. (2021). Building information modelling and energy simulation for architecture design. *Applied Science, 11*, 2252.
9. Carvalho, J. P., Almeida, M., Bragança, L., & Mateus, R. (2021). BIM-based energy analysis and sustainability assessment—Application to Portuguese buildings. *Buildings, 11*, 246.
10. Trombadore, A., & Calcagno, G. (2022). Mediterranean university as catalyst for eco-sustainable renovation: The experience of med-EcoSuRe cross-border living lab. In A. Sayigh (Ed.), *Sustainable energy development and innovation. Innovative renewable energy*. Springer.
11. Trombadore, A., Calcagno, G., & Pierucci, G. (2020). Advance smart cities through Digital Twins expanding the knowledge and management capacity of public buildings stock for energy efficiency rehabilitations. In *Contesti - Città Territori Progetti* (pp. 129–139). Firenze University Press.

Leachability of Spent Chromated Copper Arsenate (CCA)-Treated Wood Encapsulated in Geopolymer Cement

Elmira Katoozi, Jong-Leng Liow, Amar Khennane, and Gloria Pignatta

1 Introduction

Timber is a natural, renewable material but susceptible to environmental damage. To extend its useful life and minimize deterioration, wood preservatives have been used for more than 2000 years. Chromated Copper Arsenate (CCA) is one of the commonly used waterborne inorganic wood preservatives that can extend the service life of timbers by more than 40 years [1]. Despite initial beliefs about the strong bond of the CCA elements to the wood cells, depletion of arsenic has been reported during service [2–5]. Subsequently, various countries, including Australia, have classified CCA-treated woods as hazardous materials and introduced regulations to limit their application. As a result, CCA-treated wood can only be used in places without direct contact with the human body [6, 7].

Despite the restrictions placed on the application of CCA-treated timbers, disposal of these timbers remains a concern since a significant amount of them are already in service. The Environment Protection Agency of South Australia (EPA-SA) has estimated a need for the annual disposal of 160,000 m^3 of CCA-treated timber over a period of at least 20 years [8]. The Queanbeyan-Palerang council charges A$108–186 per ton of building waste disposed [9], and in the Australian Capital Territory, the cost of general commercial waste disposal is A$174 per ton [10]. In Australia, CCA-treated timbers are still being disposed of with other commercial wastes. Nevertheless, if the regulations change, this disposal cost will increase

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dramatically. According to the Western Wood Preservers Institute report, by changing the regulations to consider treated wood as hazardous waste in California, the cost of disposal will increase from US$61 to US$291 per ton [11]. The associated cost of disposal lends itself to the possibility of recycling CCA-treated wood being economically feasible.

Decontaminating CCA-treated wood and reusing the clean material in a secondary product is an environmentally promising alternative for eliminating these hazardous wastes. The decontamination process can be done by chemical remediation, bioremediation, or electrodialysis. Each method has been investigated under a range of operational conditions [12–16] but has failed to consider its economic and environmental aspects. The use of green chemicals for the decontamination process suggests that organic acids would be more eco-friendly than inorganic acids, despite their slightly weaker decontaminating ability [17]. Bioremediation and electrodialytic processes require either a long operating time [18] or expensive chemicals, with preparation costs [12] that are not economical for commercialization when compared to chemical remediation with organic acids.

Among the organic chemicals studied for the CCA removal process, oxalic acid has been shown to be the most effective in removing arsenic and chromium. Adding sodium hydroxide during the process has been found to accelerate copper removal but adds to the cost [19, 20]. Two critical determinants for a feasible and economical process are the lower acid concentration and the ability to reuse the decontaminated wood. Reuse options for decontaminated CCA wood chips can be categorized into three main groups: laminated timbers, wood panels, and wood composites [21–23].

Geopolymer cement (GPC) is an environmentally friendly substitute for Ordinary Portland cement (OPC) [24]. Given its equivalent or higher mechanical properties over OPC, it is commonly investigated to fabricate structural elements. Geopolymer materials are the result of the reaction of an alkali solution with aluminosilicate. One of the natural sources of aluminosilicate is fly ash which is an industrial by-product. Using this by-product will save on the consumption of natural resources as well as reduce the carbon dioxide footprint. Moreover, GPC has various other benefits, including high acid and sulfate resistance, low drying shrinkage, higher fire resistance, and high compressive strength [25, 26]. Manufacturing a wood-cement composite with GPC and wood chips has the advantage of having a lighter product, improved thermal conductivity, and fixture function [27]. These properties extend the use of this material to sustainable building envelope applications [28].

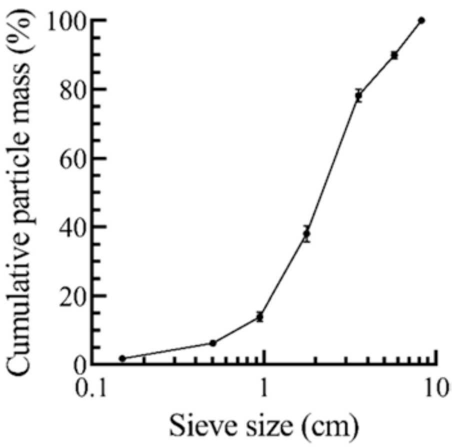
The leachability of CCA elements from the secondary products is an important factor in ensuring their environmental safety. This has been investigated only by a few authors [29, 30]. In this study, a process for decontaminating CCA-treated wood chips was studied on a pilot-plant scale and compared with laboratory-scale results to ascertain that technical-grade chemicals can be used instead of analytical-grade chemicals. The decontaminated wood was then used for the manufacture of GPC wood blocks. GPC blocks were also made with the same wood species but without decontamination. The extent of leaching of the CCA elements from the GPC-wood blocks was evaluated to determine the hazard level of the blocks. The results of this study provided an environmentally safe alternative for the disposal of CCA-treated timbers.

2 Material and Methods

2.1 CCA Decontamination

Pinus radiata CCA-treated timber was supplied from a vineyard in Griffith, Australia. The timbers were in service for at least 20 years and needed replacement. In the pilot-scale CCA decontamination process, batches of two kgs (on a dry basis) of randomly chipped wood were contacted with 40 litres of 0.05 M technical grade oxalic acid solution (solid/liquid ratio = 50 g/L). The particle size distribution of the wood chips is shown in Fig. 1. Tap water heated to 45 ± 2 °C was used throughout the experiment. The reactor was insulated with Styrofoam sheets to reduce heat loss during the process. The liquid phase temperature was recorded periodically to ensure minimal heat losses, and the maximum recorded temperature loss per run was less than 5 °C for all the experiments. A four-blade mixer connected to a Parken drill press, running at 300 rpm, kept the solution thoroughly mixed. A 16 M technical-grade sodium hydroxide solution was used to increase the pH. The reaction time was 250 minutes, during which seven samples were taken at 30, 60, 90, 120, 180, and 240 minutes of reaction, with the last sample at 250 minutes. In the last 10 minutes, the pH of the solution was increased from 1.8 to 3.2 by adding 50 mL of sodium hydroxide solution and allowing the reaction to continue. On completion, the solid was filtered with a polypropylene filter. The decontaminated wood chips were washed with 20 litres of water to remove the remaining CCA, and then oven dried. In total, 12 kgs of wood chips were decontaminated in six batches.

Fig. 1 Particle size distribution of wood chips



For the laboratory experiments, all the operational conditions, including the solid: liquid ratio, were similar to the pilot plant experiments except that analytical grade chemicals were used with double-distilled water. Ten grams of randomly chipped wood were decontaminated at a fixed temperature of 45 °C in a water bath. The solid and liquid phases were separated by vacuum filtration through a Whatman filter paper No. 541. The initial and final CCA concentrations in the wood chips were obtained by total digestion, performed according to Method #2 of the American Wood Protection Association Standard [31]. The CCA concentration in the liquid samples was measured with ultraviolet-visible (UV-vis) spectroscopy. At least three replicates were performed for all experiments.

2.2 *Geopolymer Cement Composite Mix Design*

To fabricate a wood-cement composite for sustainable building envelope applications, the decontaminated CCA-treated wood chips, and contaminated wood chips were mixed with geopolymer cement (GPC). The ingredients and raw materials used for the fabrication of the GPC are as follows:

- Class F fly ash, the aluminosilicate raw material sourced from the Australian Eraring Power Station (NSW),
- Ground granulated blast furnace slag (GGBFS),
- Wood chips,
- Sodium metasilicate pentahydrate (Na_2SiO_3),
- Sand,
- Water.

Table 1 lists the mix design of the wood-cement composite studied and its weight composition expressed as component-to-binder ratio, where the binder weight is considered equal to one, and the binder is made by mixing fly ash and GGBFS.

The chemical composition of the fly ash used to fabricate the GPC consists of about 70% of silica (SiO_2), 20% of alumina (Al_2O_3), and calcium oxide (<15% CaO), among other minor components (i.e., Fe_2O_3, K_2O, TiO_2, Na_2O, MgO, and P_2O_5). The chemical composition of the GGBFS, another by-product of iron production, consists of CaO (41%) and SiO_2 (35%), and minor components including Al_2O_3, MgO, and TiO_2.

The fabrication of the GPC prototype followed the procedure presented by Junaid, Khennane and Kayali [26] for producing low calcium alkali-activated fly ash-based concrete. The samples were cured at the laboratory temperature (i.e.,

Table 1 Mix design of the geopolymer cement composite (component to binder ratio by weight)

Material	Binder		Wood chips	Na_2SiO_3	Sand	Water
	Fly ash	GGBFS				
GPC	0.400	0.600	0.100	0.240	2.00	0.505

Fig. 2 Decontaminated CCA-treated wood-based geopolymer cement composite

23 °C with 45% ± 5% relative humidity) and cast in four bars of dimension 25 × 25 × 120 mm (Fig. 2).

2.3 CCA Leaching from GPC-Wood Blocks

Three standard tests are used to measure the hazard level of waste in construction and demolition debris (C & D) landfills and municipal solid waste (MSW) landfills. They are the accelerated evaluation of preservative leaching (AEPL) [32], the toxicity characteristics leaching procedure (TCLP) [33], and the synthetic precipitation leaching procedure (SPLP) [34]. AEPL is a laboratory evaluation of the leachability of waterborne preservatives. TCLP determines the mobility of the elements by reproducing the leaching conditions in C & D landfills. SPLP is designed to determine the mobility of elements by reproducing acid rain conditions when waste is disposed of in an open area [15]. For the AEPL test, six GPC-wood cubic blocks of sides 1.9 cm and a nominal volume of 6.9 cm^3 were cut from the GPC-wood samples, contacted with 300 mL of fresh double-distilled water, and stirred at 30 rpm in a shaker bath. The sampling intervals were 6 hours, 1, 2, 4, 7, 9, 11, 14, and 16 days providing a total of nine leachate samples. At each sampling time, the solution was replaced with fresh water, and the cumulative leaching rate was calculated. For the TCLP test, the GPC blocks were reduced in size so that the narrowest dimension was smaller than 1 cm, and 100 g of samples were contacted with two litres of the extraction fluid, which is a mixture of 11.4 mL glacial acetic acid and 128.6 mL sodium hydroxide (1 M) diluted to two litres with water, for 18 hours in the shaker bath with an agitation speed of 30 rpm. The same procedure was used for the SPLP test, except that the extraction fluid was a diluted mixture of H_2SO_4/ HNO_3 (60/40 weight percent) with a pH of 4.2.

3 Results and Discussions

Initial concentrations of As, Cr, and Cu in the wood were 4.53, 4.21, and 3.9 mg/g of wood, respectively. Equation (1) was used for calculating the fractional removal (X_i) of the CCA elements, where W is the concentration of elements in mg/g of wood, and *i* denotes Cu, Cr, or As. The subscripts total, leachate, washed, and wood represents the initial CCA content, liquid phase content after the reaction, washing solution, and the remaining content in wood chips after the reaction, respectively.

$$X_i = \frac{W_{i,\text{leachate}} + W_{i,\text{washed}}}{W_{i,\text{total}}} = \frac{W_{i,\text{total}} - W_{i,\text{wood}}}{W_{i,\text{total}}} \quad (1)$$

3.1 CCA Decontamination

The removal rate of CCA from the wood chips for the pilot-scale and lab-scale experiments (Fig. 3) showed that 60% of As was removed from the wood chips in the pilot-scale experiments. As time progressed, As removal was much lower relative to the laboratory-scale results (Fig. 3a), which might be due to the heat losses lowering the temperature in the pilot-scale experiment. In the laboratory experiment, As removal was still increasing after 180 minutes of reaction but fell slightly thereafter in the pilot-scale condition. Nevertheless, the technical grade chemicals only had a 15% difference in As removal content. Increasing the pH in the last 10 minutes of the reaction led to a slight reduction in the removal of As, showing that the leaching of this element is higher in highly acidic solutions.

Removal of Cr (Fig. 3b) showed a similar trend where the final percentage of Cr removed was 54% and 61% for pilot-scale and laboratory-scale experiments, respectively. This slight difference between the results might be due to the slight cooling observed in the pilot-scale condition. Similar to As removal trend, Cr removal ceased after 180 minutes for both experimental conditions. The pH increase at the end of the reaction did not change the Cr removed.

Cu removal (Fig. 3c) showed a similar removal trend for both pilot and lab-scale experiments. Before the pH increase, Cu removal was 35% and 39% for pilot and lab-scale experiments, and it occurred within the first 30 minutes of contact time,

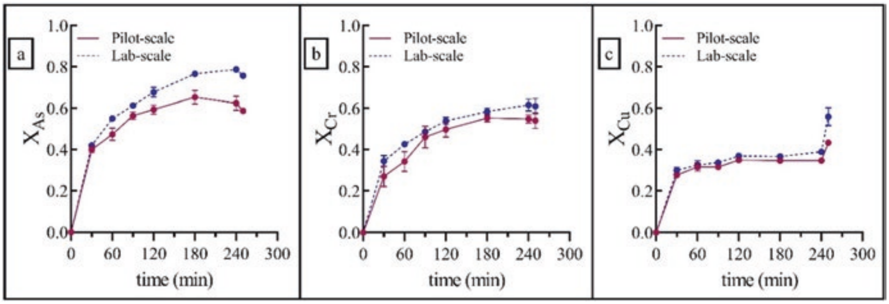


Fig. 3 Fractional removal of CCA with 0.05 M of oxalic acid at 45 °C under pilot-scale and lab-scale conditions for (**a**) arsenic, (**b**) chromium, (**c**) copper

whereafter removal of Cu stopped. Increasing the leachate pH to 3.2 and continuing the reaction for 10 minutes resulted in the fraction of Cu being removed to 45% for pilot-scale tests and 56% for laboratory-scale tests in 10 minutes, confirming the strong dependence of Cu dissolution with increasing pH.

3.2 CCA Leaching from GPC-Wood Blocks

The US Code of Federal Regulations [35] stipulates that, for the safe disposal of waste, the leached As and Cr concentration should be less than 5 mg/L in AEPL, TCLP, and SPLP tests. Figure 4a shows the CCA leachate concentration from GPC samples in mg/kg of blocks for the AEPL test. The dashed lines represent the leaching rate for the blocks produced with decontaminated wood, while the solid lines represent the blocks containing contaminated wood chips. The leaching data are also presented in mg/L in Fig. 4b. Figure 4 shows that for both types of blocks, As had the highest leaching rate, followed by Cr, confirming the higher mobility of As [36]. In the initial stage of the experiments, As leached more rapidly from the decontaminated blocks because the pre-decontamination process broke the strong bonds between CCA elements. From day 11, As leaching from the decontaminated blocks ceased while the contaminated blocks continued to leach and passed the limit of 5 mg/L. These results indicate that GPC-wood blocks manufactured with contaminated wood chips are an environmental hazard. Hence, contaminated wood chips are unsuitable for recycling into GPC-wood blocks.

The Cr and Cu leaching rates for both blocks were relatively similar, and their cumulative amounts leached did not exceed the environmental limits of 5 mg/L at the end of the experiment. Figure 4 shows that all three elements in the decontaminated blocks were below the 5 mg/L limit, confirming the possibility of reusing decontaminated CCA wood chips in GPC-wood blocks.

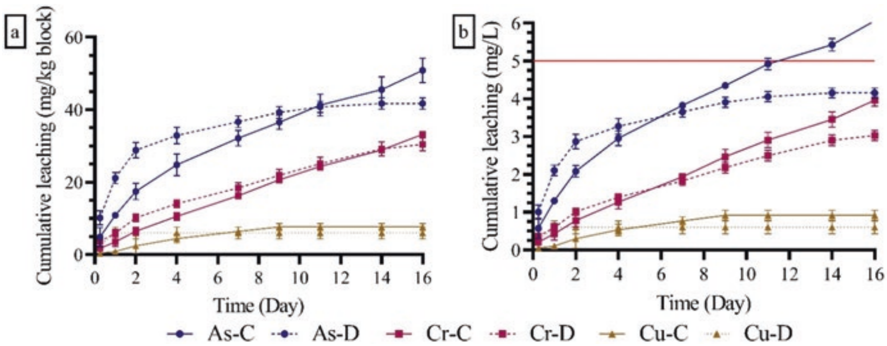


Fig. 4 CCA leaching rate for the AEPL test (**a**) based on mg/kg of blocks (**b**) concentration based on mg/L. * C: Contaminated block, D: Decontaminated block

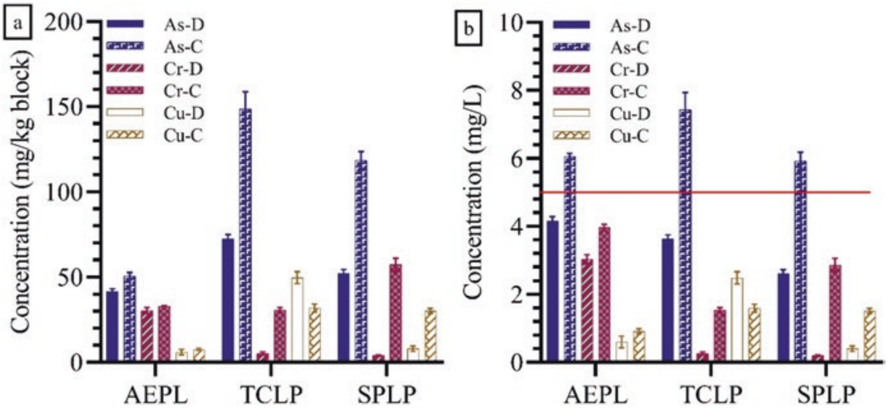


Fig. 5 CCA leaching on three tests of AEPL, TCLP, and SPLP (**a**) based on mg/kg of blocks (**b**) concentration based on mg/L. *C: Contaminated block, D: Decontaminated block

Results of the TCLP and SPLP tests on CCA leaching from GPC blocks, as well as the final cumulative leached amount from the AEPL test, are presented in Fig. 5. Similar to the previous section, these results are shown both in mg of CCA elements per kg of blocks (Fig. 5a) and mg/L (Fig. 5b). The red line in the right-side figure represents the acceptable environmental limit for As and Cr leaching. In both TCLP and SPLP tests, the leaching of As from the GPC-wood blocks made with contaminated wood chips was above the acceptable environmental limits, reaching a maximum of 8 mg/L in the TCLP test. Although As was removed from the decontaminated block, it did not exceed the 5 mg/L limit in any of the three tests.

Cr and Cu leaching from the contaminated blocks was higher than from the decontaminated blocks in all three tests but did not exceed the environmental limits. Therefore, As leachability is a major concern and pre-treatment is a necessary step in the re-use of the CCA-treated wood chips.

4 Conclusion

In this study, CCA elements were partially removed from CCA-treated spent timbers on a pilot-scale test, where low acid concentration and low operating temperature were found to provide an environmentally safe product. The conditions used resulted in 60%, 50%, and 40% of the As, Cr and Cu, respectively being removed from the wood chips. The pilot-scale experiments were also compared with the laboratory-scale experiments under the same operational conditions but with analytical-grade chemicals. Except for As, which registered a 15% reduction in removal in the pilot-scale tests, the removal of Cu and Cr was similar under both conditions. The partially decontaminated wood chips were used to produce GPC-wood blocks as a possible sustainable reuse option for building envelope applications. For comparison, a block was made with CCA-treated wood chips without any pre-decontamination process. Three basic leaching tests, the AEPL, TCLP, and SPLP, were performed to measure the mobility of CCA elements from GPC-wood blocks. In all three tests, more As was leached than Cr or Cu from the samples. However, for the decontaminated blocks, the As, Cr and Cu values were below the acceptable limit of 5 mg/L. Thus, wood-geopolymer cement blocks manufactured from partially decontaminated CCA wood chips provide an environmentally safe reuse of CCA-treated spent timbers. Conversely, the results from all tests of the blocks made with contaminated wood chips gave an As leach content above the acceptable environmental limit of 5 mg/L, even though the Cr and Cu leached content was below this limit. Therefore, CCA-treated timbers cannot be used in a secondary product without a pre-decontamination process. Further studies are suggested to evaluate the various ratios of wood chips in wood-cement blocks as well as to determine the optimum ratio for use in building envelope applications. To reduce the leach liquor as an environmentally hazardous waste stream, the recovery of CCA elements from the leach liquor would be the next logical step for a circular economy. It can be concluded that a sustainable, and environmentally safe alternative for the disposal of CCA-treated timbers is feasible.

References

1. Read, D. (2003). *Report on copper, chromium and arsenic (CCA) treated timber*.
2. Lebow, S. (1996). Leaching of wood preservative components and their mobility in the environment: Summary of pertinent literature. *General Technical Report FPL, 93*, 28 cm.
3. Townsend, T., et al. (2003). Chromium, copper, and arsenic concentrations in soil underneath CCA-treated wood structures. *Soil & Sediment Contamination, 12*(6), 779–798.
4. Vogeler, I., et al. (2005). Environmental risk assessment of CCA leaching from treated vineyard posts. In *HortResearch client report*.
5. van der Kallen, C. C., Gosselin, M., & Zagury, G. J. (2020). Oral and inhalation bioaccessibility of metal(loid)s in Chromated Copper Arsenate (CCA)-contaminated soils: Assessment of particle size influence. *Science of the Total Environment, 734*, 1–10.
6. APVMA. (2003). *Arsenic timber treatments (CCA and arsenic trioxide) review scope document*. Australian Pesticides and Veterinary Medicines Authority.
7. CSIRO. (2011). *The facts about CCA treated timber*. Commonwealth Scientific and Industrial Research Organisation.
8. EPA-SA. (1999). *Review of the landfill disposal risks and potential for recovery and recycling of preservative treated timber*. Environment Protection Agency of South Australia.
9. Quenabeyan-Palerang Council. (2021). *Fees and charges 2020–21*.
10. ACT Government. (2022). *Waste and recycling fees 2021–22*.
11. Smith, S. T. (2003). *Economic analysis of regulating treated wood waste as hazardous waste in California*.
12. Chang, Y. C., Choi, D., & Kikuchi, S. (2012). Enhanced extraction of heavy metals in the two-step process with the mixed culture of Lactobacillus bulgaricus and streptococcus thermophilus. *Bioresource Technology, 103*(1), 477–480.
13. Choi, Y. S., et al. (2013). Optimization of bioleaching conditions for metal removal from CCA-treated wood by using an unknown Polyporales sp KUC8959. *Journal of Environmental Management, 121*, 6–12.

14. Clausen, C. A., & Smith, R. L. (1998). CCA removal from treated wood by chemical, mechanical, and microbial processing. In *Proceedings of the 4th international wood preservation symposium* (p. 98–50101).
15. Janin, A., et al. (2009). Optimization of a chemical leaching process for decontamination of CCA-treated wood. *Journal of Hazardous Materials, 169*(1–3), 136–145.
16. Sarahney, H., Wang, J., & Alshawabkeh, A. (2005). Electrokinetic process for removing Cu, Cr, and as from CCA-treated wood. *Environmental Engineering Science, 22*(5), 642–650.
17. Kakitani, T., et al. (2006). Designing a purification process for chromium-, copper- and arsenic-contaminated wood. *Waste Management, 26*(5), 453–458.
18. De Castro, R. J., et al. (2021). Electro-removal of copper, chromium, and arsenic from chromated copper arsenate treated waste wood. *Engenharia Sanitaria E Ambiental, 26*(2), 211–219.
19. da Costa, L. G., et al. (2022). Biological and chemical remediation of CCA treated eucalypt poles after 30 years in service. *Chemosphere, 286*, 131629.
20. Kakitani, T., et al. (2009). Characteristics of a bioxalate chelating extraction process for removal of chromium, copper and arsenic from treated wood. *Journal of Environmental Management, 90*(5), 1918–1923.
21. Clausen, C. A., Muehl, J. H., & Krzysik, A. M. (2006). Properties of structural panels fabricated from bioremediated CCA-treated wood: Pilot scale. *Forest Products Journal, 56*(3), 32–35.
22. Janowiak, J. J., et al. (2014). Mechanical performance of nail-laminated posts manufactured from reclaimed chromated copper arsenate-treated decking lumber. *Forest Products Journal, 64*(1–2), 55–63.
23. Liow, J., et al. (2022). Recycling of chrome-copper-arsenic timber through cement particleboard manufacture. In *Role of circular economy in resource sustainability* (Sustainable production, life cycle engineering and management) (pp. 111–122), Springer, Cham.
24. Tang, W. X., Pignatta, G., & Sepasgozar, S. M. J. S. (2021). Life-cycle assessment of fly ash and cenosphere-based geopolymer material. *Sustainability, 13*(20), 11167.
25. Duxson, P., et al. (2007). Geopolymer technology: The current state of the art. *Journal of Materials Science, 42*(9), 2917–2933.
26. Junaid, M. T., Khennane, A., & Kayali, O. (2015). Performance of fly ash based geopolymer concrete made using non-pelletized fly ash aggregates after exposure to high temperatures. *Materials and Structures, 48*(10), 3357–3365.
27. Berzins, A., et al. (2017). Mechanical properties of wood-geopolymer composite. *Engineering for Rural Development, 16*, 1167–1173.
28. Pignatta, G., et al. (2022). Can geopolymer materials be optimized for sustainable building envelope applications? A preliminary development and characterization study. *Environmental Sciences Proceedings, 12*(1), 11.
29. Kamdem, D. P., et al. (2004). Properties of wood plastic composites made of recycled HDPE and wood flour from CCA-treated wood removed from service. *Composites Part A-Applied Science and Manufacturing, 35*(3), 347–355.
30. Li, W., Shupe, T. F., & Hse, C. Y. (2004). Leaching of flakeboard produced from recycled CCA-treated wood into deionized water. *Forest Products Journal, 54*(3), 38–41.
31. AWPA-A7. (2019). *Standard for wet ashing procedures for preparing wood for chemical analysis*.
32. AWPA-E11-16. (2016). *Standard method for accelerated evaluation of preservative leaching*. American Wood Protection Association Standard.
33. US-EPA. (1992). *Method 1311. Toxicity characteristic leaching procedure*. US Environmental Protection Agency.
34. US-EPA. (1994). *Method 1312. Synthetic precipitation leaching procedure*. US Environmental Protection Agency.
35. CFR. (2012). *Code of federal regulations title 40: Protection of environment*. 27.
36. Lebow, S. T., Morrell, J. J., & Milota, M. R. (1996). Western wood species treated with chromated copper arsenate: Effect of moisture content. *Forest Products Journal, 46*(2), 67–70.

Behind a 'Senseable' Green Building: The New Sistema Ambiente Headquarter

Antonella Trombadore, Gisella Calcagno, and Juan Camilo Olano Salinas

1 Introduction

Among the many critical urban borderscapes, industrial sites exemplify different challenges in the transition toward a sustainable built environment: at the outskirts of cities, they usually coast natural landscapes, often as a problematic breaking point characterized by grey infrastructures connecting unfinished or obsolescent buildings in different shades of low-quality environmental conditions (from soil degradation, to noise and pollution, e.g. brownfields). Moreover, considering that for their nature productive buildings host potentially impacting industrial processes consuming energy at a much higher rate than conventional buildings [1], and that actually conventional buildings are energivores [2], their sustainable regeneration is a big challenge to address the ambitious Sustainable Development Goals. Working in industrial areas means to consider the Clean Energy imperative to contrast Climate Change, but also to ensure Health and Well-being in Sustainable Communities and Cities. At the level of the European Union, the need to regenerate urban spaces and existing buildings is clearly stated in the Green Deal, in the Renovation Wave as well as in the New EU Bauhaus program envisioning sustainable, inclusive and beautiful cities. As much as a challenge, the requalification of industrial areas is an opportunity to explore more integrated architectural, urban and landscape practices, able to address the complexity of the design task by jointly work towards sustainability goals.

Beyond green-washing operations, well-founded regenerative design practices can transform existing industrial areas to co-evolve within living systems, making

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them able to activate positive relationships both with the natural environment (e.g. landscape protection and carbon footprint reduction), as well as with humans, ensuring health and well-being for workers and communities, also supporting more appropriate economic models (from green to circular economy).

2 Regenerate Industrial Areas: A Challenge and an Opportunity

Since the 90s, the globally recognized effort to make industrial development sustainable can be traced in the international definition and promotion of Eco-Industrial Parks (EIPs), as "dedicated areas for industrial use at a suitable site that supports sustainability through the integration of social, economic, and environmental quality aspects into its siting, planning, management and operations" [3]. Nowadays, best Green practices of Eco-Industrial Parks are spreading worldwide, where the pivotal role of landscape, urban and architectural design to reach ambitious sustainability objectives can be observed in the diffusion of industrial buildings/areas certified by the most influential sustainability assessment methods and rating systems (e.g. Breeam and Leed). However, looking at the Mediterranean area, few examples are available, and this fact requires a serious reflection.

In the Italian context, notwithstanding the early adoption of a national legislative framework on Eco-Industrial Parks (APEA – Aree Produttive Ecologicamente Attrez-zate, art. 26 D.lgs 112/98), we cannot speak of a diffuse culture of sustainability in actual 'industrial-scapes', in particular if we consider that they are usually located in between beautiful natural landscapes and as much beautiful historical cities. Observing the Tuscan level, maybe not for a case the region of the ambitious architectural competition here proposed, the national definition of APEA has been further implemented through regulations and guidelines which strongly support sustainable planning and green infrastructures, to complement as much sustainable management and operational practices [4].

3 A New Green Building in the Industrial Area of Lucca: The Design Competition

The aim of this paper is to share the design experience behind the winning project of an Italian architectural competition for a new Green Building in the industrial district of Lucca (Tuscany). The design process described refers to the two-phase architectural competition launched to find the best solution for the new Sistema Ambiente Spa Headquarter, a company with prevalently public capital carrying out Urban Hygiene Services in the municipality of Lucca.

The competition asked to design the new headquarter inside an unfinished warehouse located in the industrial area of S. Piero a Vico, object of an ongoing urban requalification, coasting the fluvial landscape of the rural Lucca Plain some kilometers NE from the great historical city-center. It required to efficiently adapt to the existing structure (covering a surface of 4.400 m^2 approx.), and the external space around (for a total area of 12.500 m^2) (Fig. 1), to address a complex functional program, combining representative and technical activities, from public reception, offices, and collateral semi-public spaces (e.g. auditorium) to several technical spaces for the waste management and the maintenance of the company's vehicle fleet, requiring particular attention to potential noise and pollutions.

The competition posed ambitious targets, requiring the project to reach:

- High-profile architectural redevelopment, paying particular attention to recognizability and the corporate identity, as well as to landscape integration
- High energy efficiency (target of Nearly Zero Energy Buildings), integrating passive systems and sustainable management of water resources and greenery and taking into account a recognized sustainability protocol for the subsequent certification
- Circular economy objectives, through a careful choice of the origin of the construction materials, in full compliance with CAMs (national Minimum Environmental Criteria)
- Healthiness, with high levels of internal comfort in terms of air quality, acoustic and lighting

To reach the NZEB target, the design challenge was to organically upgrade the envelope of the existing structure, built in 2010 with prefabricated panels in

Fig. 1 Intervention area with the existing building to be renovated in the industrial district of Lucca

reinforced concrete (with very-low thermal performances), and to combine with an efficient plant-system consuming energy from renewable sources installed on site.

4 Behind the Winning Project: The Design Process

Designing towards ambitious energy efficiency and environmental quality targets (Nzeb and Leed pre-certification) in an industrial area required an integrated urban, landscape, architectural but cultural common approach since the beginning of the interdisciplinary design process [5, 6]. Deeply rooted in the principles of regenerative sustainability, the foundation of the project was to conceive the new Green Building not only to respond to the high energy and environmental performances, but to remark the pivotal role of nature for humans in terms of health, comfort, well-being and sociality, by composing a recognizable image, an icon of high esthetical quality, communicating sustainability.

To address the ambitious challenges posed by the competition, the design process required the coordination of a project team characterized by strong interdisciplinarity (architects, urban and landscape designers, structural and energy engineers, experts in energy and environmental issues, as well as fire prevention and security coordinators, geologists, agronomists). The effort to integrate and valorize the different disciplinary contributions was supported by the early adoption, since the first phases of the design process, of BIM (Building Information Modeling) methodologies and digital tools to simulate integrated scenarios and guide data-driven decision-making [7]. A smooth and pro-active co-design process was possible by the common enthusiasm and commitment towards sustainability, with consolidated, experienced and shared green design principles.

4.1 Behind the Project Concept: A Common Cultural and Regenerative Background

The ecological concept behind the new Sistema Ambiente Spa headquarter, inspired by the same company's name (transl. 'System Environment') and continuously inspiring the whole design process, was to conceive the new Green Building as an eco-system co-evolving with nature and humans, and continuously feeding their mutual interaction.

The new building is designed as a 'living organism' with its own efficient and virtuous metabolism capable of activating positive connections with both the sourrounding natural [8] and human-made environment, supporting the revitalization and attractiveness of the industrial area, along with the integration in the fluvial landscape of the Lucca Plain. Rooted in the Mediterranean culture of living, the choice was to sustain the reciprocal nature-humans interaction by exploiting the natural resources of sun, wind, water and vegetation as ‘living building materials’, combined in a mix of passive and active technological solutions to improve not only the environmental performances of the building (reducing energy consumption and the effects of pollution while increasing biodiversity) but also to optimize the quality of use for humans (mitigating the microclimate and increasing comfort and well-being).

Although they are pivotal in the Mediterranean urban, architectural, historical and cultural tradition, nature-based solutions are even more recognized as game-changers towards sustainable buildings and cities [9]. Re-naturalizing urban spaces to accelerate the ecological transition is the pervading global approach of planners and architects: the dominant idea is that the integration of nature-based solutions (NBS) can restore a new balance and a new relationship with nature. Deepening the knowledge of the systemic man-nature relationships, and embracing regenerative and biophilic design approaches [10], the concept idea was ambitious: buildings as ‘environ-mental systems’ can close and sustain a virtuous circle where nature and man can harmonically co-evolve, increasing the levels of environmental sustainability and improving the human well-being by stimulating their senses. Going further, in line with the pro-active company’s mission towards sustainability, the design process was merged with a strong communication strategy, envisioning the Green Building as a virtuous model/living laboratory triggering a chain of values on environmental sustainability’s awareness for actual and future generations.

4.2 Concept Design Phase: Designing with Nature

On the basis of the common premises and worldviews, the project team exploited a consolidated multi-disciplinary knowledge and adopted shared methodologies on bioclimatic design in the Mediterranean socio-climatic context [11]. The strategic use of the four natural resources of sun, wind, water and vegetation as special building materials was the guiding concept integrated since the first phases of the urban, architectural and landscape design process:

- Sun: exploring the geometry of the solar path in the specific project location, solar radiation has been considered for both its thermal energy and natural daylight, trying to balance the benefits of passive thermal contributions (direct solar radiation and greenhouse effect), with the effects of shadow (natural cooling), such as to maintain high levels of visual comfort (reduction of glare and better distribution of daylight) in indoor environments;
- Wind: considering prevalent winds, natural ventilation strategies (cross-ventilation, chimney effect, air flows) are optimized to favor the activation of convective motions accelerating the exchanges of exhausted-fresh air and of thermal energy, improving the indoor air quality, minimizing the use of mechanical ventilation systems, and naturally thermo-regulating spaces, reducing the cooling energy demand;

- Water: the hydric resource is highly valorized by exploiting traditional passive systems in combination with wind and vegetation (water basins for evaporative cooling), and through the water-sensitive design of sustainable urban drainage systems (SuDs) to address a sustainable water re-cycle;
- Vegetation: green elements (trees, shrubs, plants and climbing plants) are integrated as dynamic, adapting and natural systems of control and modulation of solar radiation (as shading and cooling devices), to optimize the indoor/outdoor microclimate, ensuring acoustic and olfactory quality (to reduce pollution and protect human health and comfort), as well as on a perceptive and psychological level.

The combined positive contribution of the four natural elements has been exploited in the architectural, urban and landscape design through the integration of both traditional Mediterranean passive strategies and innovative green technologies in the new Green Building's envelope and surrounding external spaces (Fig. 2). Harmonically addressing the competition's ambitious challenges of energy efficiency, environmental quality, healthiness and circularity, natural elements as building materials mitigate the new Green Building in its proximity context, acting as a 'green resewing' that mediates the actual critical border between the urban (industrial) and natural landscape (the river and the valley).

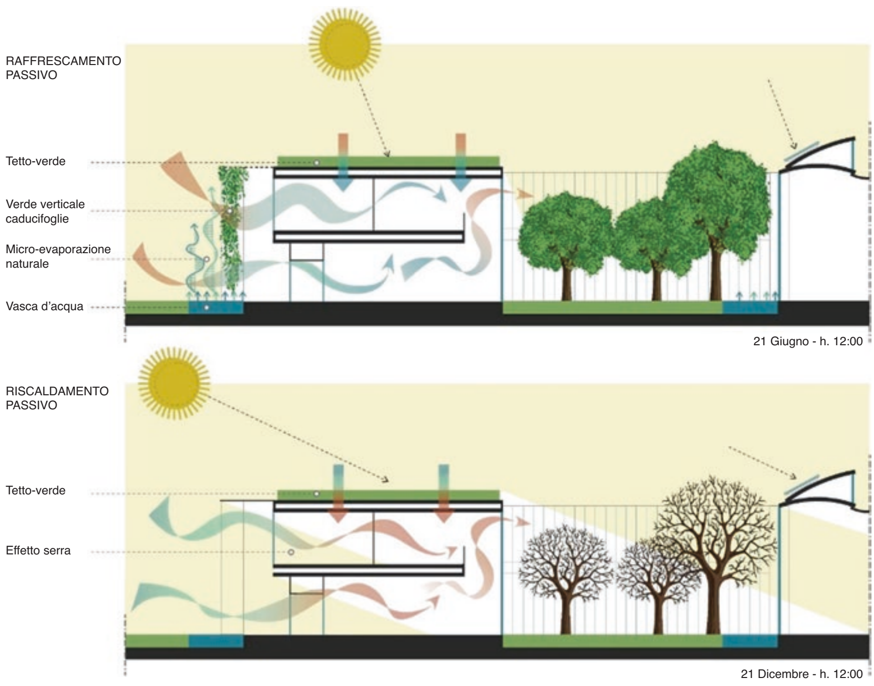

Fig. 2 Bioclimatic building sections (summer and winter solstices)

4.3 Architectural Project: A New 'Senseable' Green Skin

The architectural design proposal responded to the need of combining very different functional requirements by composing a new architectural narrative that, taking roots into the existent to envision the new Green Building, speaks about sustainability.

The existing unfinished warehouses to be deeply renovated have typological and architectural elements characterized by uniformity, modularity and repetitiveness, texture and typical color of prefabricated elements, typical of industrial buildings in the peripheral areas of Italian medium cities. What was missing is a volumetric hierarchy, a functional articulation of interior spaces, and a connective and distributive fabric, such as an appropriate modulation of opaque and transparent surfaces.

The main front of the existing building has an orientation of 45° with respect to the solar thermal axis: overhanging the roof on the main front of the building, a large portico has been defined, marking the main entrance and framing the long slat of offices to protect its transparent surface. The portico, architectural typology-bioclimatic device of the Mediterranean climate context, acts as a modulator of solar radiation and passive cooling accelerator; it was sized to prevent the risk of summer overheating and maximize the passive winter energy supplies. The vertical septa orient solar radiation following its path at the different times of the day (east-west) and the rhythms of seasons (Fig. 3). Between lightness and shadows, the portico covers a parallel water basin, contributing to the passive-bioclimatic strategy (daylight reflection and wind mitigation), opened in the central part and running around a new entrance square to welcome officers, workers and citizens.

To enhance volumetric dynamism, the portico's vertical elements are reduced in their size, de-materializing and re-naturalizing them with climbing plants in filiform supports that expand on the lateral fronts, enhancing the modular layout and rhythm of the whole existing envelope. Starting from greater density and materialization on the 'back of the building', where technical activities are located (presses and washing), the green skin leads to the dematerialization, transparency and lightness in the entrance portico, open to the wide public (Fig. 4).

All the natural resources enter inside the existing structure: subtracting a central portion of the massive volume, it was possible to articulate spaces around a central

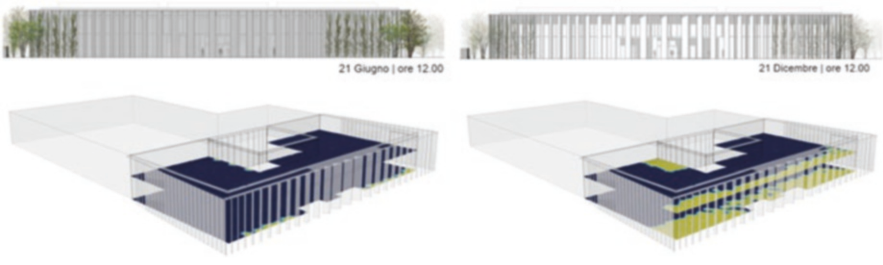

Fig. 3 Daylight analysis for the design of the portico's vertical septa (summer and winter conditions)

Fig. 4 View from the entrance garden to the principal façade

courtyard (patio), hearth and 'green lung' of the new headquarter. With the same language of the external new skin, vegetation and water are integrated to enhance the well-functioning of the building, favoring a passive improvement of the micro-climate (homogeneous distribution of light natural and cross ventilation). The green courtyard contents to re-establishing a visual connection between inside and outside, by offering natural views in all the interior spaces (i.e. public reception and technical areas - Fig. 5). Permeable to nature and following its cycles, the 'seaseable skin' is eventually intended to stimulate positive sensory and psychophysical perceptions.

The low-performance existing envelope is renovated by the means of a green roof-passive device, insisting upon the head of the building where high thermal performances are required (administrative and representative area), and vertically by integrating the infill system with metal panels insulated with different layers according to the thermal requirements of the very different functional areas (offices, auditorium or cafeteria), also compared with these kinds of 'plug-in' solutions.

The prefabricated dry-construction system with a high percentage of recycled raw materials (with products certified EDP - Environmental Product Declaration) was chosen for a more sustainable construction site, high flexibility along the building's future life-cycle, and for the possibility to finally disassemble, recover and recycle. To cover the not-heated technical spaces, metal panels are dematerialized in expanded metal sheets, whose transparency consents to mitigate the most technical spaces and to integrate into the green new skin running around.

4.4 *Toward Zero Energy and Environmental Impacts*

Developed under the principles of regenerative sustainability and Mediterranean bioclimatic design, the integrated urban, landscape and architectural project permitted a significant reduction of the energy demand for the new Green Building. Passive

Fig. 5 View on the internal courtyard: from the reception area (left) and from the working one (right)

strategies combining the four natural resources of sun, wind, vegetation and water consented to passive thermal gains, maximization of thermal storages and insulation in the winter period, and control of solar radiation, natural ventilation, mitigation of microclimate (reducing the heat island effect, also using reflective surfaces) in the summertime. Given this advantageous point of departure, the highly strategic choice was to focus exclusively on electricity as energy supply for heating, cooling,

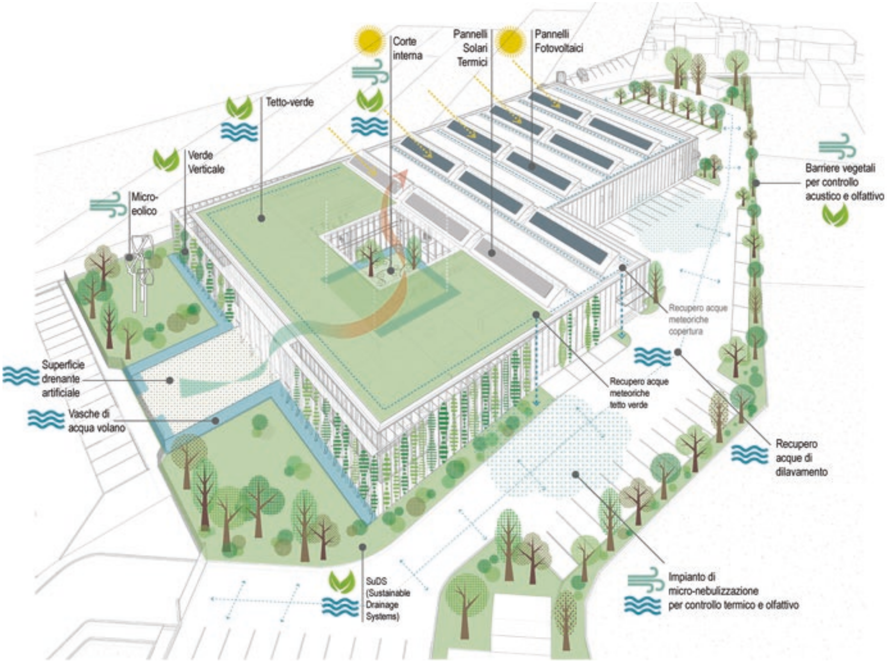

Fig. 6 Synthetic representation of the nature-based solutions adopted

lighting and equipment: avoiding other supply fossil energy systems, heat pumps are powered by a photovoltaic system integrated into the sawtooth roof over the technical area of the building, consenting to directly exploit renewable solar energy with an annual production reaching the Nzeb targets. As demonstrative and iconic, but supporting the requirements of renewable energy, three micro-wind turbines are located in the entrance square. Furthermore, solar thermal panels are installed on the roof to meet the hot water demand for sanitary use and to support the water supply for technical washing of vehicles, also contributing to the operation of the heat pump in the summertime (Fig. 6).

The project is particularly attentive to water management aspects and provides for various recovery and reuse systems. Rainwater of different types is treated separately according to the type and then conveyed to collection tanks: the rainwater of the green roof is drained and filtered by the different layers that make up the package; the rainwater from the rest of the roof and runoff from the external waterproof surfaces is conveyed inside SuDS (Sustainable Drainage Systems) for a mechanical and biological filtering and purification process.

5 Conclusion

Even if historically and widely recognized as an absolute benefit for both human beings and the planet, the integration of nature in the existing built environment still requires comprehensive consideration, and valorization, in interdisciplinary co-design processes. Embracing and innovating the Mediterranean culture, the adoption of nature-based but technological solutions in integrated design processes needs to be strongly sustained by validated methodologies and tools to fully capture, and demonstrate, the impact of natural elements in living spaces: their contribution to improving human well-being and on reducing the building ecological footprint.

Nowadays, nature-based solutions as sustainable regenerators of buildings and cities can be supported by the exploitation of the even more large availability of quantitative and qualitative data along the design process, to scientifically analyze and quantify benefits and opportunities. The data-driven approach appears particularly profitable for an integrated design process oriented to the integration of nature-based solutions in the existing built environment: on the basis of an attentive survey and evaluation of actual data and conditions, comprehensive simulations of feasible scenarios can be run since the first phases of the design process, guiding a more efficient decision making.

As the winning design project for the Green Headquarters testified, green and digital transitions can be blended in a virtuous circle, with the digital domain enabling data-rich and predictive processes of co-planning and co-design, where to calculate in a scientific way and sustain even more ambitious scenarios in terms of environmental quality and sustainability. The design process behind the new project was in fact highly supported by the exploitation of BIM, consenting to optimize the workflow by means of a digital model (with information related to geometry, materials, performances of the existing building, as well of the future one) shared among the various disciplinary teams and connected with dedicated simulation software, according to the various disciplinary aspects.

Going further, as envisioned in the design proposal, it should be possible to enforce the innovative content of the new Green Building by experimenting with Digital Twin [12], a virtual replica of the building where it is possible to combine technical static data (BIM model) with real-time environmental data fed by sensors located in the real-life context (buildings and urban spaces) and connected with IoT systems, which also consent to take into account, and interact with, the end-user experience. They can be exploited to measure the human and environmental benefits deriving from green technologies, making people aware of the positive contribution of ecological solutions in the built living spaces.

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Service Plant Design: Studio 3Energy Associati (Ing. Marco Aronne, Ing. Matteo Santambrogio, Per. Ind. Pietro Daniele Silvestri); Structural Design: L2 Progetti Srl (Ing. Luca Ferrario, Ing. Luca Zampatti); Agronomic Consultancy: Dott. Agr. Fiorella Castelluccio; Hydrogeological Consultancy: Studio Conti Associati (Dott. Geol. Antonio Conti, Dott. Geol. Vincenzo Giannone, Dott. Ing. Francesco Bocchio); Environmental Sustainability and Energy Efficiency Consultancy: beXLab - DIDA Department of Architecture, University of Florence (Prof. Antonella Trombadore, Arch. PhD Gisella Calcagno, Arch. MSc Juan Camilo Olano Salinas).

References

1. World Bank. (2021). *International framework for eco-industrial parks* (Vol. 2). Washington, DC.
2. United Nations Environment Programme. (2021). *2021 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector*. Nairobi.
3. Caroli, M., Cavallo, M., & Valentino, A. (2015). *Eco-industrial parks A green and place marketing approach*. Luiss University Press.
4. Gallo, P. (2013). The organisational model of the APEA for eco-friendly and competitive territorial governance. *TECHNE - Journal of Technology for Architecture and Environment, 5*, 86–94.
5. Lombera, J. T., & Rojo, J. Q. (2010). Industrial building design stage based on a system approach to their environmental sus-tainability. *Construction and Building Materials, 24*(4), 438–447.
6. Loures, L., & Panagopoulos, T. (2007). Sustainable reclamation of industrial areas in urban landscapes. *WIT Transactions on Ecology and the Environment, 10*, 791–800.
7. Jalei, F., Jalei, F., & Mohammadi, S. (2020). An integrated BIM-LEED application to automate sustainable design assessment framework at the conceptual stage of building projects. *Sustainable Cities and Society, 53*, 1–18.
8. Mang, P., & Reed, B. (2012). Designing from place: a regenerative framework and methodology. *Building Research & Information, 40*, 23–38.
9. Somarakis, G., Stagakis, S., & Chrysoulakis, N. (Eds.) (2019). *ThinkNature nature-based solutions handbook*. ThinkNature project funded by the EU Horizon 2020 research and innovation programme under grant agreement. No. 730338.
10. Yeang, K. (2020). *Saving the planet by design. Reinventing our world through ecomimesis*. Routledge.
11. Trombadore, A. (2015). *Mediterranean Smart Cities. Innovazione tecnologica ed ecoefficienza nella gestione dei processi di trasformazione urbana*. Altralinea Edizioni s.r.l.
12. Trombadore, A., Calcagno, G., & Pierucci, G. (2020). Advance smart cities through Digital Twins expanding the knowledge and management capacity of public buildings stock for energy efficiency rehabilitations. *Contesti - Città Territori Progetti, 1*(2020), 129–139.

Towards the "Museum of the Future": From Heritage Building Information Modelling to Virtual Reality for the Valorization of the Built Heritage of the City of Rabat

Youssef El Ganadi, Sharif Anouar, and Adam Anouar

1 Introduction

Digital technologies can make a tangible contribution to the promotion of Islamic material and immaterial cultural heritage. They can broaden the scope of use of historical heritage. The ICESCO, an international organization for the promotion of Islamic culture in the world, has felt the great potential of new digital technologies through which the objectives of conservation, enhancement, and promotion of Islamic cultural heritage in the world can be achieved. In 2021, the organization designated Rabat as the "Culture Capital of the Islamic World 2022", thanks to the rich and varied Islamic cultural heritage, and identified the museum of the future as the ideal tool to promote the cultural heritage of the capital of the Kingdom of Morocco. As theorized by ICESCO, the museum of the future is a place where the physical and digital space merge to enhance knowledge, enriched through interaction and creativity. Among the digital technologies that can contribute to the practical definition of the museum of the future, Heritage Building Information Modelling, Scan-to-BIM, and Virtual Reality (VR) are the significant ones. In this chapter, we will try to give shape to the concept of the museum of the future by defining a logical workflow that includes a series of tools for the realization of the physical and digital exhibition.

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2 Rabat – Culture Capital of the Islamic World

Islam is one of the main monotheistic religions (it has about two billion followers). It is a heterogeneous whole that gathers different components such as religious practices, way of life, and culture, which is an important aspect. Islam is therefore not only a religion but also a culture, an art, and an architecture. Most scholars of Islamic art share the idea that religion and Islamic culture are two inseparable elements [1].

Over time, Islamic culture has influenced not only the way of life of millions of people, the art, and architecture of Islamic and non-Islamic countries but has also influenced the spatial organization of cities. Contrary to the idea put forward by some scholars of the Arab-Islamic Medina arguing that Islamic cities were a spontaneous creation without a blueprint, recent studies based on the analysis of ancient texts have proven that the builders of the Medina were already using established plans [2].

The city of Rabat is a clear example of an Islamic city organized according to the Arab-Islamic pattern of the Medina and which has preserved its rich Islamic cultural heritage. The capital of the Kingdom of Morocco has a very long history of almost 2500 years which contains a legacy that depicts various historical periods and the presence of different cultures. Given its strategic position at the mouth of the river, the city has been, throughout history, the main centre of interest by settled or passing peoples. An important phase in the urbanization of the Kingdom of Morocco is attributed to the Almohad people. During their reign, several urban centres were built, including Rabat [3]. Thanks to its rich and varied cultural heritage, Rabat has obtained an important recognition by being registered as a UNESCO World Heritage Site in 2012.

3 The Museum – Between Past and Future

The International Council of Museum focuses on three key words: accessibility, communication, and learning. Currently, most museums have certain limitations that contradict the definition given by ICOM, such in the case of accessibility which has been greatly impacted by the last pandemic. Covid-19 has made it impossible to have a physical presence in all public space such as museums by making them inaccessible for a long time. According to a recent UNESCO survey “Museums around the world in the Face of the COVID-19 Pandemic”, 90% of museums (about 85,000 museum institutions) have closed and about 10% will not reopen. Only a small number of museums and museum professionals have been able to demonstrate resilience in the face of the pandemic by providing cultural content through innovations [4]. Even UNESCO in its recommendations (2015) encourages museum institutions to adopt technologies to enhance cultural contents.

Digital technologies can be the right medium to make a museum more accessible even in exceptional cases like the pandemic and reduce the distance allowing everyone to enjoy an exhibition or a show, which is more communicative and entertaining for the visitor. Another important aspect concerns the question of learning and what and how a visitor selects and uses the content displayed in a museum. According to Falk et al., the public does not learn what we intend them to learn; it is just that the nature of learning in museums is rarely as simple as we think. Given the free-choice nature of museum experiences, visitors are very selective about what they want to learn, and these decisions are heavily influenced by what they already know and what interests them [5].

Technologies can radically change the usability and communication of content offered by a museum for learning purposes. For example, with a digital platform, the visitor can choose the content and the way of using it through a series of interactive applications such as Virtual Reality (VR) and Augmented Reality (AR) that make the visitor's experience more accessible, simple, and fun.

Even large multinational technology companies have long understood the potential of digital technologies to create multimedia content that can be used via web platforms. Thanks to the intuition of Amit Sood, the actual director of Google's cultural institute, the American tech giant has managed to combine technology and art by providing, since 2011, an innovative application called Google Art & Culture which offers virtual tours of the most famous museums and galleries in the world such as the British Museum in London or the Guggenheim in New York. The application offers two varied content usable from home through immersive virtual reality that allows you to visit famous exhibitions like the Egyptian hieroglyphs at the British Museum. Neil MacGregor, director of National Gallery, London, talked about the partnership signed with Google to join the "Google Art & Culture" initiative; he says that the "Google Art & Culture" project to make the works exhibited in the most famous museums accessible is not only a question of accessibility but rather a mean to offer new ways to use it to better appreciate art and the works on display [6].

The head of business strategy for libraries and museums of Microsoft, Catherine Devine, argued that technology cannot and should not replace the primary function of a museum, because it only makes sense if it provides an added value [7].

3.1 The Roving Museum of the Future: A Model in the Making

The museum of the future has the general objective of teaching visitors about a specific topic for more knowledge and awareness. Digital technologies can change the ways of using and learning in a museum, and we try to immerse the visitor in a virtual space that gives him the freedom to opt for specific contents of interest and with the possibility to change perspective, environment, and content at the speed of a click. In 2016, a European Union–funded research project was titled Mu .SA (Museum Sector Alliance) with the aim of defining the model of the museum of the future. Mu .SA is a consortium of higher education institutions, independent and national research centres, cultural and social associations and organizations, and a broad European network.

In the Muse project, a first definition is given: "the museum of the future will opt for a virtuous mix of direct storytelling (the museum tells itself) and indirect storytelling (visitors tell the museum), in favour of participatory storytelling. Individuals, both the public and its staff, are encouraged to create their own stories and connections to the museum itself and the history it represents" [8].

The idea of the Museum of the Future was then taken up by ICESCO which understood the great potential of digital technologies for promoting Islamic culture around the world through a new model of museum, the museum of the future. ICESCO states, "With the rise of technology over the past two decades, the simple concept of a museum has been challenged and redefined. Times of turmoil such as today's show the changing faces of museums, contemporary technology is transforming museums from spaces of observation and learning to spaces of intention for participation and involvement" [9].

ICESCO places technology at the centre of its strategy to achieve its goals. It unfolds in nine areas of interest; each one is considered a container that includes a series of actions and projects. One can also find different areas (technological innovation, heritage protection, dialogue, and cohabitation) involved in the same project such as in the Museum of the Future which is the subject of our current work. ICESCO's projects and actions include the theoretical and practical definition of the "museum of the future for the promotion of Islamic culture and art, a hybrid space (digital and physical), a place of knowledge, interaction and creativity" [9].

The primary goal of this research is to establish a distinct model for the museum of the future, setting it apart from the ones proposed by Google and ICESCO. It envisions an itinerant museum exhibition, both physical and virtual, that can travel to various remote locations in Morocco to promote and showcase the cultural heritage of Rabat on a national scale. The exhibition offers virtual and physical 3D models on a small scale and, thus, is easily transferable to places such as the desert and mountainous areas of the Atlas Mountains which are remote, isolated, and lacking in technology for access to museums and exhibitions.

The research proposes as a specific objective the definition of a practical framework (process and technological tools) for the realization of the virtual and physical museum exhibition of the Islamic culture for the city of Rabat using the necropolis of Chellah as a case study. The technologies proposed in this research concern HBIM, virtual reality, and 3D printing.

4 Case Study: Chellah’s Gate

In this research, Chellah, one of the symbols of the rich heritage of the city of Rabat, was chosen as a case study. The site of Chellah (Fig. 1) is located on a plateau outside the walls of Rabat and adjoins the Bouregreg River which flows into the Atlantic Ocean. The site includes vestiges belonging to the Phoenician and Roman periods, to which the Islamic period was later added. The area was used by the Romans in the time of Trajan to develop a colony that took the name of Sala Colonia. This name was later arabized to its current name of Chellah. During the Islamic rule, the sultan of the time (Abu Yusif Yacoub) was fascinated by this place and decided to build a necropolis for his dynasty. The Romans and then the Moors contributed to make the necropolis of Chellah a magical place, a symbol of coexistence between different cultures and architectures in which the animal and vegetable kingdom also finds its place. The objective of the following research is the definition of a workflow for the development of the virtual and physical exhibition of the museum of the future in Rabat.

The workflow used is broken down into four different phases (Fig. 2). First, a documentary analysis was performed, followed by a scan using a laser scanner to

Fig. 1 The necropolis of Chellah

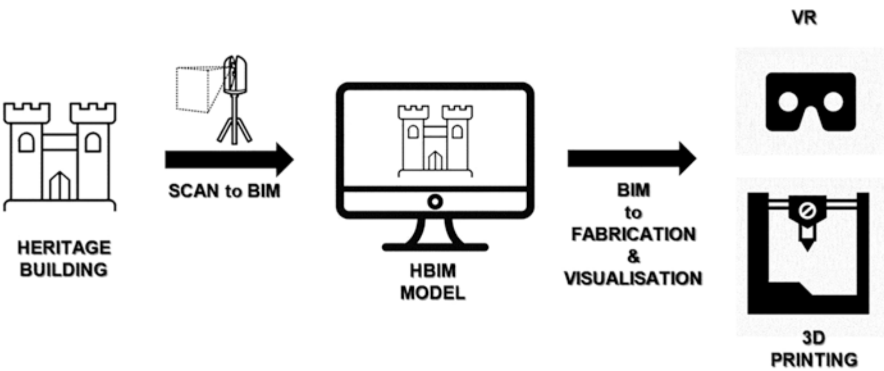

Fig. 2 HBIM to VR workflow

acquire geometric data. The acquired point cloud was used to create the HBIM model which served as the basis for creating immersive virtual tours using VR. In addition, the 3D printer technology was used to produce physical models at the scale of the object chosen for the case study, i.e., the portal of the Chellah necropolis. The different phases of the workflow will be explained in the following sections.

4.1 HBIM Process

For the realization of a parametric model, reference is made to an innovative process called Building Information Modelling (BIM). It is a difficult concept to define because it concerns a vast sector such as the AEC industry (architecture, engineering, and construction) and involves a network of professionals and researchers belonging to different technical and scientific fields. In this research we will refer to one of the 10 most shared definitions by the scientific community and that is of Bilal Succar, one of the leading experts, who states that "Building Information Modelling (BIM) is a set of policy interactions, processes and technologies that generate a "methodology to manage the essential design and project data of the building in digital format throughout the building life cycle" [10].

Currently, BIM is not only used for the design and construction of new buildings, but it has also been extended to historic buildings and monuments (Heritage-BIM or HBIM). The unknown is the effectiveness of the BIM methodology in the conservation and enhancement of historical heritage. The benefits of BIM are known, but it is not yet clear whether the BIM methodology can be applied to the historic heritage sector [11].

There is no doubt that BIM methodology can bring great benefits to the historic heritage sector. BIM methodology integrated with VR technology is radically changing the way historic cultural heritage is used and how to bridge the gap between heritage and citizens. It must be said that there are also negative aspects regarding the HBIM methodology, namely the high cost of the hardware and software used as well as the slow process of developing the reconstructed virtual model.

The process of elaboration of the data is carried out using the chart Business Process Model Notation (BPMN) (Fig. 3). The figure shows the analysis phase as the first step which, as indicated by Pocobelli et al., is a key phase, during which a great diversity of information sources needs to be well combined [12].

The analysis of the building encompasses two parallel actions – the first one includes documentary research, whereas the second one relies on the surveying of the heritage building conducted with photogrammetry and laser scanner. The result of this technology is a cloud of points that will serve as a basis for the creation of the BIM model (Fig. 4). Regarding the survey of Chellah's gate, a FARO laser scanner was used. The raw point cloud is exported as an e57 file in Recap pro to be rationalized, i.e. cleaned and optimized and then exported to a BIM modelling software – in the case of this work, Autodesk Revit. Going from an optimized point

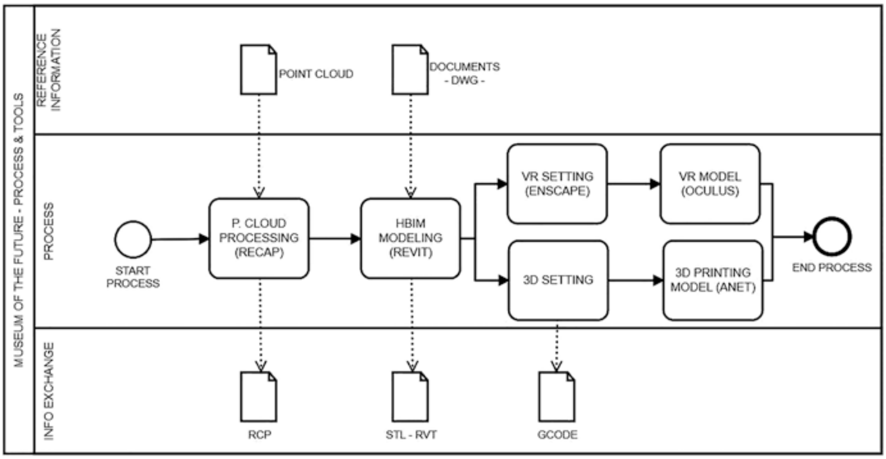

Fig. 3 Data flow using BPMN

Fig. 4 Scan-to-BIM: From left to right: Left: The survey of Chellah's gate using a Faro Laser scanner. Middle: The resulting point cloud. Right: The BIM model overlaid on the point cloud

cloud to a parametric model is laborious, slow, and complex. There is no automation to go from a series of geo-located and textured points to a parametric 3D model. Moreover, it is very difficult to find standard libraries with BIM objects, so one is forced to do on-site modelling and this makes the process very time-consuming and laborious [13].

In the process of 3D modelling of the Chellah portal, the decision was made for on-site modelling on Revit for the reasons listed above based on the point cloud, after which the assignment of dimensional parameters, materials, and physical attributes of it was carried out in parallel. The parts of the portal such as the two towers, the crown, the entrance facade, the interior hall, and the ornamentation on the walls were modelled separately. When assembled, they bring life to the gate (Fig. 5).

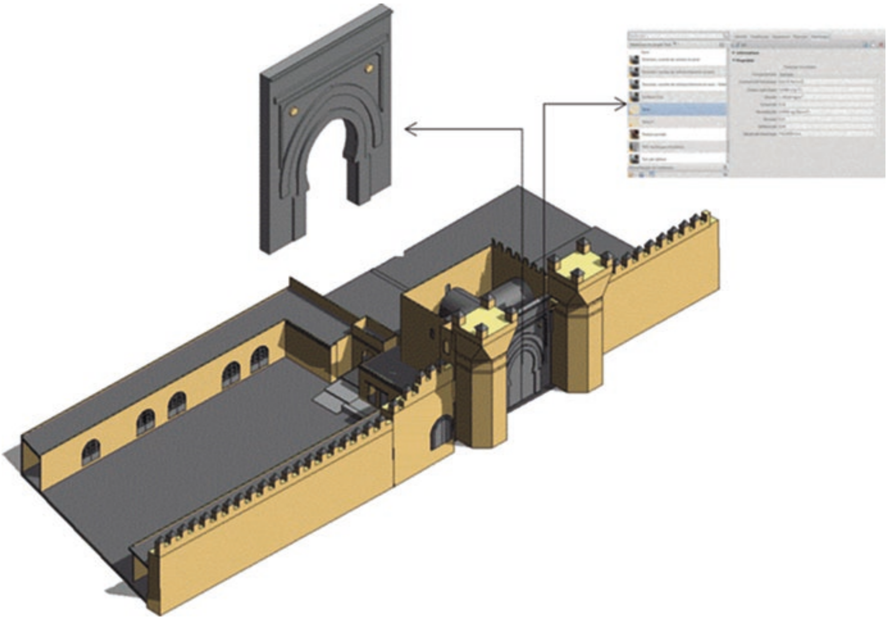

Fig. 5 HBIM model

4.2 Virtual Reality and 3D Printing

The next step in the procedure consists of the production of an immersive virtual reality experience. In the context of this research, Enscape, a GPU-based render, was chosen due to its relatively cheap pricing, ease of use, and low hardware specification requirements. Besides, it permitted to produce VR contents in different formats such as an executable and web standalone. All of which could be accessed and operated by the end-users' own hardware as it does not require any license or subscription to run on.

The implementation of the rendering software to develop a virtual reality experience is straightforward. Enscape is installed in Revit as an add-on which allows the parallel use of both software. Any modification in the Revit model is directly and seamlessly passed to the rendering software; this live synchronization gives the authors the possibility to test various scenarios in a very short amount of time. Once the lighting is set, the virtual model can be exported in either a 360 stereo image format, as a VR-compatible executable file or web standalone version.

To be able to test the files obtained, two types of head mounted displays (HMD) for VR were selected: VR headset and VR glasses. The former comes into the shape of an Oculus Quest 2 and necessitates the offline use of a rather powerful laptop if using the standalone executable file, while the web standalone eliminates the need

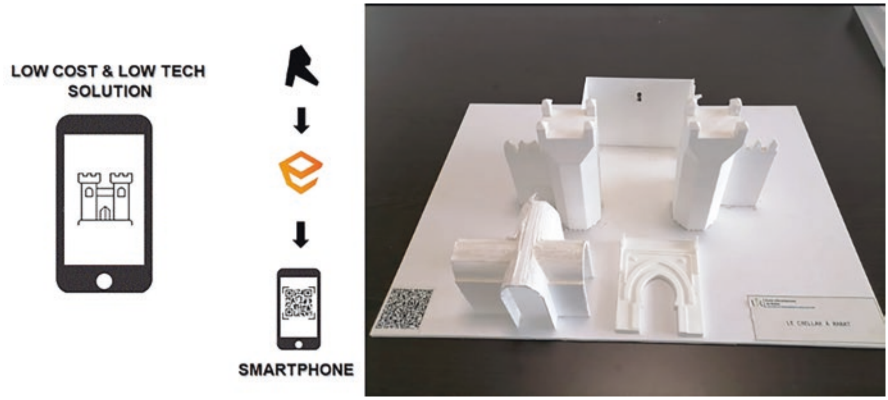

Fig. 6 QR code and the printed 3D model

of a powerful graphic card because it opens in a web-browser and renders using WebGL 2.0. The VR glasses are cheaper, less power-hungry, and more accessible to a non-tech savvy audience. They require a smartphone and need an internet connection best suited to 360° panoramas images either in mono or stereo modes. The images are exported and encapsulated in QR codes (Fig. 6). The difference in hardware impacts the type as well as the quality of the immersive experience and how the users interact with the virtual museum.

The final step towards the museum of the future is the production of a small-scale 3D-printed model based on the HBIM digital twin. 3D printing technology is now very affordable and widely used by the professional, academic, and hobbyist communities. Consumer-grade desktops bring great results at a small price, yet additive fabrication remains a very time-consuming process. Nonetheless, it allows the fabrication of complex geometries as those often found in the built heritage. The FFF 3D printer used within the framework of this work is an Anet ET5Pro with a 300 × 300 × 400 mm build volume. The 3D printing of a small-scale model using a desktop 3D printer brought up some issues that had to be considered.

The digital model developed on the Autodesk Revit platform is a faithful representation of the historic architectural artifact at a scale of 1:1. However, what constitutes an advantage in the digital realm turns to be a limitation to overcome when it comes to materialize it in a small-scale model. The major issue lies in the discrepancy between the virtual model and the fabrication constraint of the fused filament fabrication (FFF) desktop 3D printer. To print the heritage model with high precision, the Revit model is exported as an STL file and then processed through Cura, a slicer program that generates the machine code (G-code) read by the 3D printer. Multiple back and forth modifications in Revit and Cura were necessary to optimize the file to print the heritage model with high accuracy (Fig. 7).

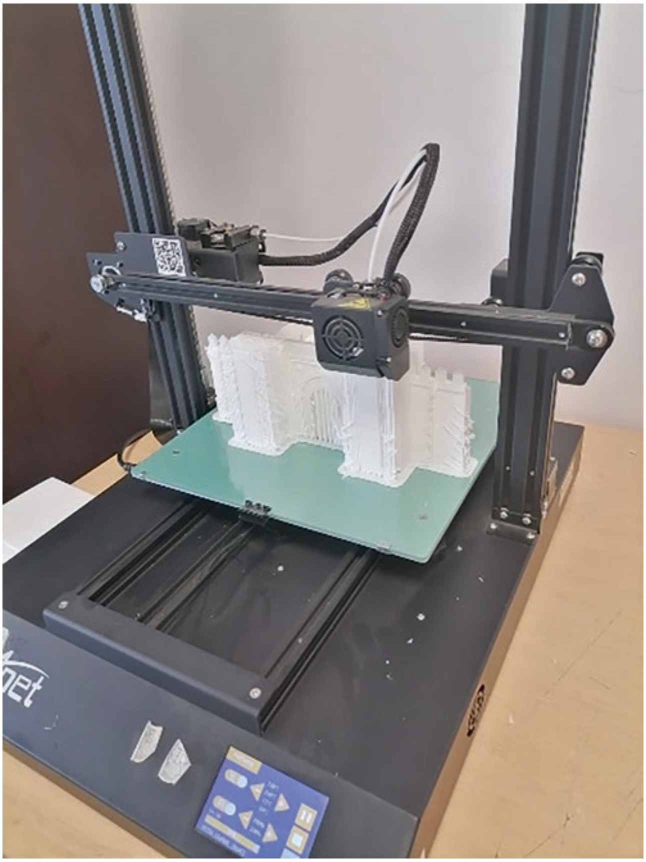

Fig. 7 3D printing of Chellah's gate

4.3 Exhibition

After weeks of development, enough digital and physical materials presenting important historical Islamic buildings located in the city of Rabat were produced. Therefore, the question of a first implementation of the concept of the roving museum of the future rose naturally. Taking advantage of an event organized by the region of Rabat in March 2022 to celebrate the capital city of Morocco – "World Heritage, 50 years of universal mobilization, 10 years of commitment in Rabat" – an exhibition coordinated by Prof. Imane Bennani has been proposed. Entitled "Digitization of the properties of the city of Rabat inscribed on the UNESCO World Heritage List" (Fig. 8), this hybrid exhibition (digital and physical) was held the entrance portal of the Oudayas, one of Rabat's main historical buildings. The exhibition received positive feedback from both officials and the public. In May 2022,

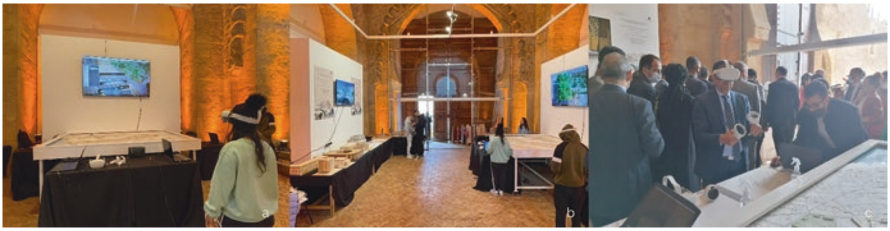

Fig. 8 Exhibition: Digitization of the properties of the city of Rabat inscribed on the UNESCO World Heritage List as a proof of concept of the roving museum of the future. (**a**) Preparation of the virtual reality experience, (**b**) hybrid exhibition, and (**c**) visitors experience. (March 2022)

the exhibition was moved for 1 week to the "Jardin botanique de Rabat", another place with great historical value where it drew many people.

5 Conclusion

This chapter materialized the concept of the Museum of the Future in relation to the valorization of the Islamic architectural heritage of Rabat. It described a streamlined workflow based on the scan-to-BIM process for HBIM and ended with the creation of virtual reality experiences and the production of 3D-printed models as means of cultural built heritage valorization. The success of the exhibitions exemplified the coherence and viability of the concept of an itinerant museum in a country like Morocco. It also opened paths for further research. One future development of this work could focus on the workflow by finding new ways to automate the generation of the BIM model to avoid a time-consuming and open to error process that still relies heavily on manual modelling and multiple software. Another avenue of research could expand the operational side of the roving museum by proposing a cross-platform application as well the reconfiguration of a small truck to host the physical contents of the museum with the objective of reaching the secluded areas of Morocco – a reminder of the Islamic caravans roaming the desert and connecting people.

References

1. Watenpaugh, H. Z. (2017). Resonance and circulation: The category "Islamic Art and Architecture". In G. Necipoglu & B. Flood (Eds.), *A companion to Islamic art and architecture* (Vol. II, pp. 1223–1244). Wiley-Blackwell, Blackwell Companions to Art History Series.
2. Abu-Lughod, J. Contemporary relevance of Islamic urban principles. *Ekistics*, *47*(280), Islamic Human Settlements (1980), pp. 6–10 (5 pages).
3. Bennani et al. (2011). *Rabat, Capitale moderne et ville historique: un patrimoine en partage*.

4. UNESCO. (2020). *Les musées dans le monde face à la pandémie de COVID-19*. Rapport UNESCO.
5. Falk, J., & Storksdieck, M. (2005). Using the Contextual Model of Learning to understand visitor learning from a science center exhibition. *Science Education, 89*(5), 744–778.
6. MacGreogor, N. (2015, November 12). *Evening Standard*.
7. Devine, C. (2021). *A look to the future: Microsoft Mesh and beyond*. MuseumNext.
8. Kameas, A. (2020). *The future of museum professionals in the digital era – The Success Story of Mu.SA*. Hellenic Open University Press.
9. ICESCO.
10. Succar, B. *The five components of BIM performance measurement*.
11. Historic England. (2017). *BIM for heritage developing a historic building information model*. Historic England.
12. Pocobelli, D. P., Boehm, J., Bryan, P., et al. (2018). BIM for heritage science: A review. *Heritage Science, 6*, 30.
13. Barrile, V., Bernardo, E., & Bilotta, G. (2022). An experimental HBIM processing: Innovative tool for 3D model reconstruction of morpho-typological phases for the cultural heritage. *Remote Sensing, 14*(5), 1288.

Urban Resilience and Climate Change: Risks and Impacts Linked to Human Behaviours in the Age of COVID-19

Mai M. Barakat and Mohsen M. Aboulnaga

1 Introduction

Climate change is inevitable and affecting every corner of the globe. Antonio Guterres, Secretary-General of the United Nations, stated at Petersburg Climate Dialogue, which was held in Berlin, Germany, between 17 and 19 July 2022, the globe needs decisive actions to fight climate change (CC) [1]. *"This had to be the decisive climate action. That means trust, multilateralism, and collaboration. We have a choice – Collective action or collective suicide. It is in our hands."*

Facing rapid changes in the global climate is vital to mitigate 45% of carbon emissions by 2030. These changes are attributable to human behaviour [2]. Moreover, current energy and food crises add to the world's challenges. Humans produce this global impact through our use of natural resources, multiplied by the vast increase in population seen in the past 50 to 100 years. Measurements, analysis, and research are continuously conducted to mitigate the risks of CC on earth. Recently, COVID-19 has been spreading much faster than in the previous 2 years, and scientists confirm that humans' behaviour, non-resilient cities, and urban areas, in addition to CC, are the main reasons for such spread. There is a relationship between CC and recent diseases such as coronavirus; the World Health Organisation (WHO) estimated that reducing air pollution and greenhouse gas (GHG) emissions will lead to the protection of humans' respiratory system and enhancement of their lung functions which will certainly minimize the infection of many respiratory

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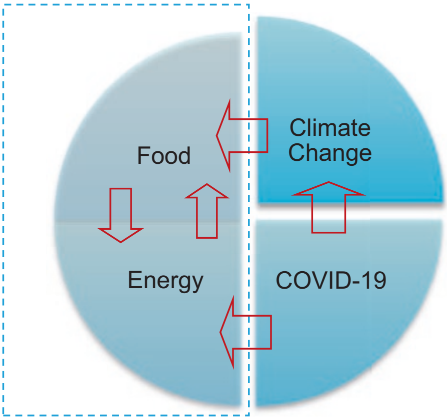


Fig. 1 World's major four crises between 2020 and 2022. (Image source: Developed by authors)

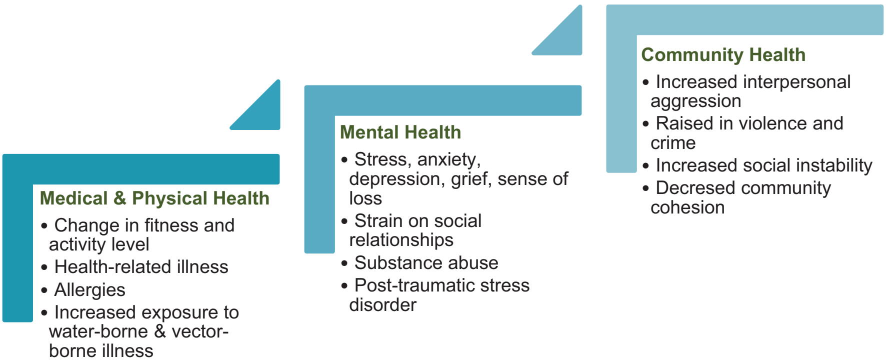


Fig. 2 Impacts of climate change on human health in the United States: a scientific assessment. (Image source: Developed by authors)

diseases such as COVID-19; hence, CC makes us ill. Figure 1 shows the main global crises.

The potential impact of population growth on climate change is much greater in countries with high emissions per capita [3]. For example, projected increases in energy use in Africa in the next 25 years are expected to result in much smaller total emissions than in other regions since this continent has the lowest regional per capita GHG emissions. In contrast, the United States now produces seven times more CO_2 emissions than Africa in addition to other emitting countries such as China, India, Russia, Japan, and Germany [4].

Despite the increasing scientific evidence, it seems that a large majority of people remain unaware, in denial, or otherwise disengaged with the problem of climate change; further impacts of climate change on humans are presented in Fig. 2. This is reflected in the fact that UK energy consumption relating to transportation and households has continued to rise in recent years. The IPCC [5, 6] suggests that human behaviour is responsible for more than half of the observed increases in the climate

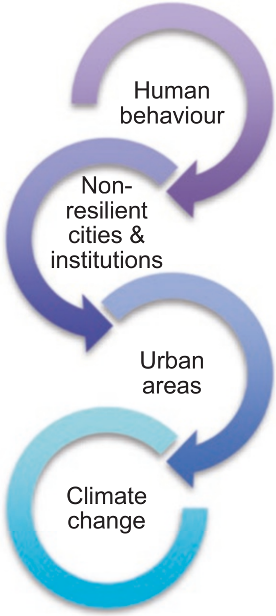


Fig. 3 Main reasons for the spread of COVID-19. (Image source: Developed by authors)

change. Elsewhere, it is also reported that only a minority of people are taking action to mitigate the effect. This means that for most individuals, daily life continues in an unsustainable way. Also, it is considered that human behaviour is one of the main reasons for COVID-19 spread in addition to other reasons illustrated in Fig. 3 [7].

Relevant research in these areas, which would be aided to greater attention by psychologists, has been reviewed. It can be concluded that the most affecting factors concerning CC are individual, societal, and behavioural predictors [8], Fig. 4 depicted these factors. Human activities are also affecting the surrounding environment locally and globally. These activities have resulted in a major increase of GHG emissions such as methane (CH_4), carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen monoxide (NO_2), which has consequently led to warming of the atmosphere and caused climate change [9]. Figure 5 illustrates the factors affecting climate change that are mainly related to human behaviour. Unfortunately, climate change has increasingly impacted humans and cities' infrastructures, causing sea-level rises, certain diseases, and natural disasters such as hurricanes, heavy storms, floods, and droughts [10].

2 Objectives

This research work aims at examining the deep psychosocial causes of human behaviour impact towards climate change, primarily by assessing the patterns of reproduction and consumption. The study also seeks to identify and distinguish individual, societal, and behavioral predictors of environmental impact [11] to find out which activities emit the highest carbon emissions.

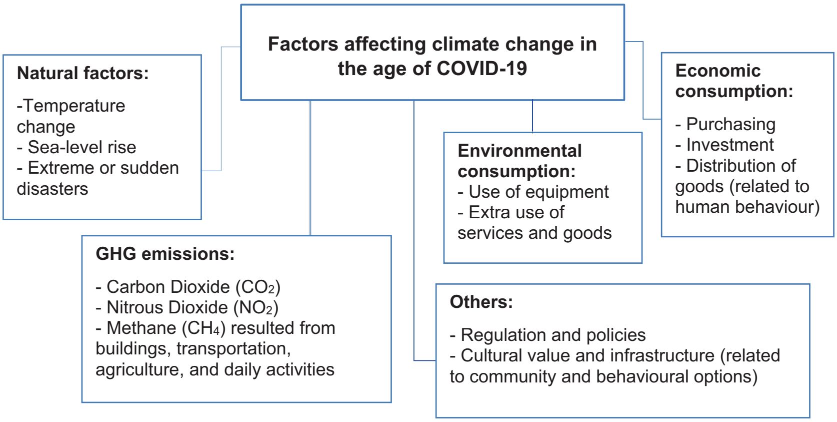


Fig. 4 Factors affecting climate change in the age of COVID-19. (Image source: Developed by authors)

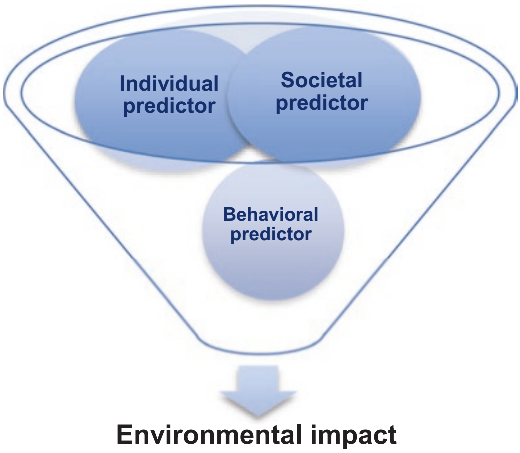


Fig. 5 Factors affecting climate change related to human behaviours and their environmental impact. (Source: Developed by authors)

3 COVID-19 and Its Effect on Humans' Behaviour

In the age of COVID-19, people's behaviour has significantly changed, mainly due to the threat and risk perception, panic, social inequality, and miscommunications, whether at work or at home between relatives, etc. [11]. These changes are summarized by statistics as follows:

(a) Residents spent 32.2% more time at home. Each person, on average, came into close contact with 17.6 and 7.1 people per day during the normal and pandemic periods, respectively.
(b) Students, workers, and older people reduced their daily number of close contacts by 83.0%, 48.1%, and 40.3%, respectively.

(c) The close contact rates in residences, workplaces, places of study, restaurants, shopping centers, markets, and public transport decreased by 8.3%, 30.8%, 66.0%, 38.5%, 48.6%, 41.0%, and 36.1%, respectively. Based on the simulation, these changes in human behaviour reduced the effective reproduction number of influenza by 63.1% [12].

The key psychological objective for most people is to keep stress at a minimum. Everyone is adapting to the new reality, which includes the fear of viral spread and contagion, self-quarantine, and supply shortages. More seriously, some are coping with illness and fear of death [13].

3.1 How Humans' Behaviour Affects the Resilience of a City

In the case of epidemics, resilience is generally about dealing with the ongoing stress and distress to keep them at a minimum during a time of crisis. This is especially true for people who fall ill. In these cases, resilience is defined as the ability to maintain a trajectory of good mental health – keeping spirits up and minimizing depression, worry, and anxiety. Unfortunately, some people under stress and worries tend to waste resources by buying unsustainable food or by ordering huge amount of food daily; others tend to take their car and keep moving around for hours with an excuse that they don't want to walk or even ride public transport for not to get infected [14]. In addition, depression and fear also made them switch on all lighting and devices, which caused a disconnection between their relatives and friends [15].

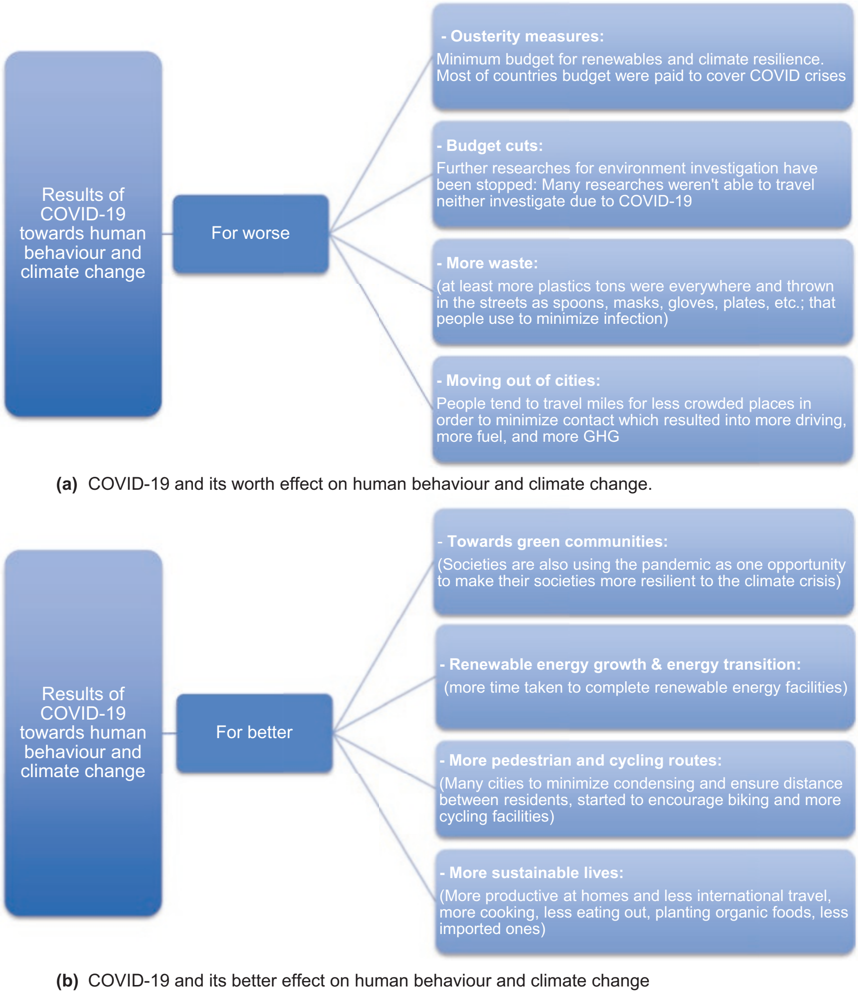
Disaster is defined as an event or occurrence that is usually sudden and unexpected. Consequently, it intensely alters the beings, objects, and localities under its influence. It results in loss of life, severe environmental damage, destruction or loss of material and goods, and disruption of normal patterns of life. Hence, the concept of resilience is widely adopted across academic and policy debates as a way of reducing society's vulnerability to threats posed by natural and human-induced disasters. According to Bruneau et al. [16], disaster resilience is the ability of social units (e.g., organizations and communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruptions. Similarly, United Nations International Strategy for Disaster Reduction (UNISDR) [17] defines resilience as 'the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner through the preservation and restoration of its essential basic structures and functions' [18]. Furthermore, disaster resilience emphasizes the processes and conditions within communities to enhance the population's ability to resist, adapt, and recover from a shock or perturbation within the shortest possible time and with little or no outside assistance.

Fig. 6 Types of disaster resilience strategies. (Image source: Developed by authors)

Disaster resilience, in this way, is often synonymous with the notions of 'bouncing back' or 'jumping back. A system is usually designed to behave in a certain way under normal circumstances. When disturbed from equilibrium by a disruptive event, the performance of the system will deviate from its design level. The resilience of the system is its ability to reduce both the magnitude and duration of the deviation as efficiently as possible to its usual targeted system performance levels [19]. The concept of resilience has two forms of strategies, namely hard resilience and soft resilience (Fig. 6). Hard resilience is defined as the direct strength of structures/institutions which are under pressure, as such increasing its resilience by specific strengthening measures could reduce its probability of collapse. In contrast, soft resilience is the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes in function or structure. It could be achieved through the flexibility and capacity of the system, rather than strengthening structures or institutions about specific stresses, as in the hard resilience approach [20]. Fiksel [21] and Rose and Liao [22] emphasize three main capacities summarized as follows: (a) absorptive capacity (the ability of the system to absorb the disruptive event); (b) adaptive capacity (ability to adapt to the event); and (c) restorative capacity (the ability of the system to recover) [23]. Cimellaro et al. [24], Ranjan, & Abenayake [25] suggest that hospital facilities as one of the attributes of a disaster resilience community. This is aligned with Proag [26] who highlights that public health and healthcare are amongst the infrastructure assets that should be contemplated as resilient. Pursuing this further, a disaster resilience hospital should be able to resist, absorb, and respond to the shock of disasters, while still retaining their most essential functionality, e.g., pre-hospital care, emergency medical treatment, critical care, decontamination, and isolation, and then recover to its original state or a new adaptive state [27].

3.2 Impact of COVID-19 on Climate Change

Beyond carbon emissions, however, COVID-19 is resulting in changes in individual behaviour and social attitudes, and in responses by governments that will have impacts on the environment and on our ability to combat climate change [28]. Many



(a) COVID-19 and its worth effect on human behaviour and climate change.

(b) COVID-19 and its better effect on human behaviour and climate change

Fig. 7 COVID-19 and its effect on human behaviour and climate change. (Image source: Developed by authors)

of these impacts make matters worse (Fig. 7a), while others make them better (Fig. 7b). However, it is unclear how these factors will balance out at the end. One thing is certain: more large-scale actions will be essentially needed to avoid the worst impacts of climate change. As a result of the lockdowns around the world to control COVID-19, huge decreases in transportation and industrial activity resulted in a drop in daily global carbon emissions of 17% in April 2020 [28]. Nonetheless, carbon dioxide (CO_2) levels in the atmosphere reacted the highest monthly average that it has ever emitted, therefore it can remain in the atmosphere for a hundred years; some of it could last tens of thousands of years [29]. Figure 7 shows how COVID-19 has affected human behaviour and climate change.

3.3 How Daily Activities Contribute to Climate Change?

Human activities are the major reasons for the rise of the unbalanced amount of GHG in the atmosphere, causing anthropogenic aspects of climate change. Many daily actions are the key contributors to the rise of the climate change crisis, such as transportation, the food industry, the burning of fossil fuels for general use, and waste which is very damaging to the atmosphere. Greenhouse gases are useful as they are responsible for trapping sun heat into the atmosphere but with limits [30]. Climate change is a natural phenomenon that results from high greenhouse gas (GHG) emissions in the atmosphere, consequently resulting in evaporation, animal respiration, waste, and volcanoes, 95 percent probability was determined that human activities heavily contributed to the warming of the planet. Figure 8 presents the impacts of climate change on cities [31].

3.3.1 Impacts of Contributing These Activities to Climate Change

Climate change is affecting human health badly, both physical and mental health. The declining quality of the air, pollution, and high temperatures make the transmission of diseases easier, resulting in many further alarming facts and challenges:

- Average planet temperature has risen by 0.9 °C.
- An increase of approximately 18 °C (0.4 °F) has been detected in the top of 700 m of oceans.
- The amount of carbon dioxide yearly absorbed by oceans is increased by two billion tons.
- The amount of air pollution, GHG emissions, and animal endangerment.

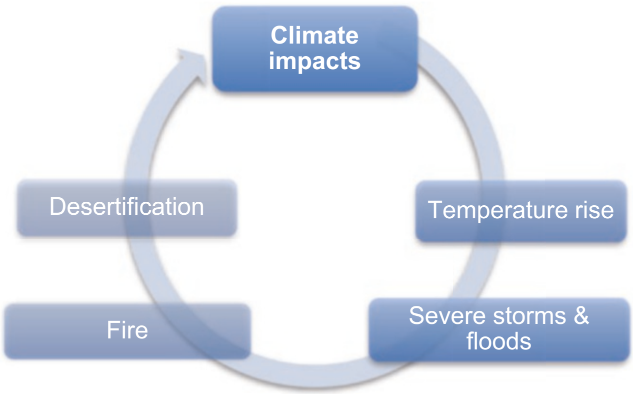


Fig. 8 Impacts of climate change on cities. (Image source: Developed by Authors) (**a**) Burned houses in the outskirts of London. (**b**) Houses on fire in London due to highest temperature

(a) Burned houses in the outskirts of London (b) Houses on fire in London due to highest record in temperature

Fig. 9 Major fires in many building and farms in the City of London, United Kingdom, due to highest temperature recorded in history. (Image credit and Source: Sky News, https://news.sky.com/story/major-incident-declared-across-london-after-huge-surge-in-fires-and-homes-destroyed-on-uks-hottest-ever-day-12655061)

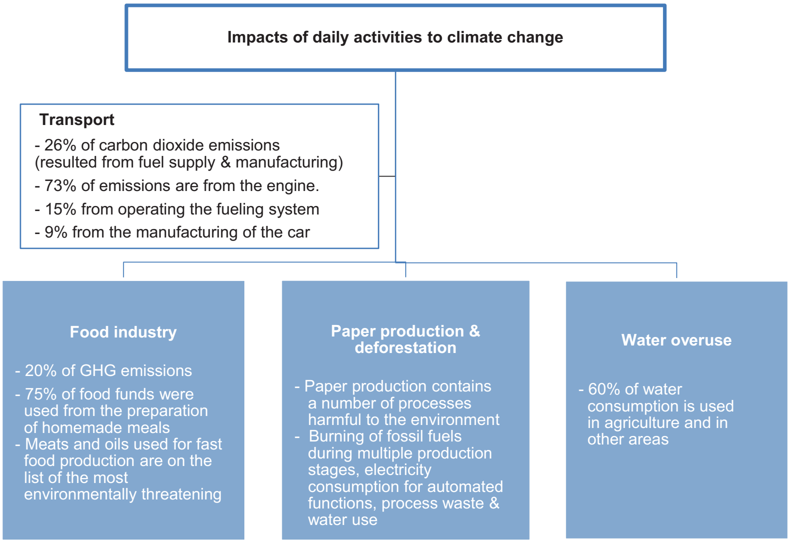


Fig. 10 Impacts of contributing daily activities to climate change. (Image source: Developed by authors)

As shown in Fig. 9, the recent impact of climate change on the United Kingdom, particularly the city of London, was a sudden and unprecedented rise in temperature, i.e., the highest temperature (41 °C in July 2022) ever recorded in history. Such impact caused many buildings and farms to catch fires (Fig. 9a, b). In a nutshell, climate change is making us ill. Figure 10 illustrates the impacts of human activities on climate change [32].

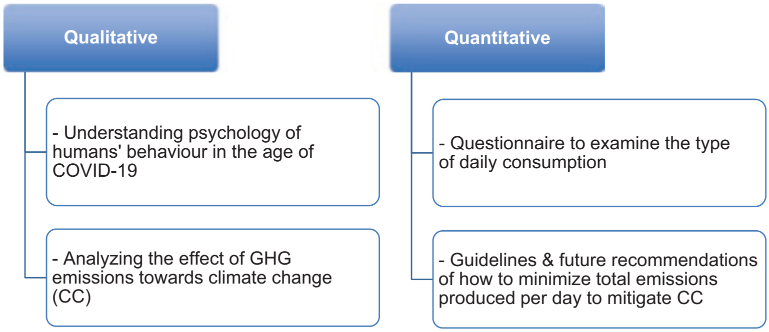


Fig. 11 The methodology adopted in the study. (Image source: Developed by authors)

4 Methodology

In this study, the methodology is based on qualitative and quantitative approaches. The first approach concentrates on understanding psychological effects and understanding of humans' behaviour after COVID-19 and how it will consequently affect climate change. This will be addressed by identifying the categories of daily activities. The quantitative approach focuses on a questionnaire that targets a random category of citizens in developing countries. Such questionnaire will assist in identifying human behaviours and calculating many parameters such as energy consumption, transportation, food, and waste as well as recycling, travel, and carbon emissions from their daily activity in order to provide a better understanding for concluding some guidelines that will enhance humans' lifestyle and contribute towards mitigating GHG emissions and ensuring urban resilience for climate change. In conducting the questionnaire, a pilot study targeted a sample of 100 people that represented three selected sets: (a) high-populated country, (b) medium-populated country, and (c) less populated country. Figure 11 shows the methodology that outlines this research work.

(a) COVID-19 and its worst effect on human behaviour and climate change.
(b) COVID-19 and its better effect on human behaviour and climate change.

5 Inequality and COVID-19

Inequality is a serious barrier to the health and well-being of people. The World Health Organisation (WHO) estimated that by reducing environmental and social risk factors, people could be prevented from being exposed to nearly a quarter global health burden (loss from sickness, death, and financial costs). Public health is a political choice, and maintaining it will reverse to more resilience, zero-carbon, and a healthier future [33].

5.1 *Making the Low-Carbon Transition Goal Part of the Post-COVID-19 Response*

As both fossil fuel and low-carbon investments are under considerable stress, policies have a particular opportunity to tilt the balance towards more sustainable energy sources. In the acute phase of the pandemic, policymakers have focused on addressing the health crisis and providing emergency assistance to households and firms. For the health crisis abates, the question is how to revive an ailing economy and generate jobs, while avoiding locking in carbon-intensive infrastructure and capital assets that will undermine long-term climate objectives? The recovery from the crisis can be harnessed to speed up the energy transition towards low-carbon cities, considering the lessons learned from previous green recovery packages adopted following the global financial crisis between 2008 and 2009.

Public policies play a crucial role in ensuring people's well-being and is at the centre of governments' agenda, especially during the age of COVID-19 recovery as well as the low-carbon transition. Such an approach will also help in boosting political and social support for more ambitious mitigation action [34]. Afterwards, policies had to summarize all GHG emissions caused by humans after COVID-19 crisis, so that they could manage energy consumption and mitigate carbon. Those categories were summarized in energy and materials, transport, food and agriculture, and land management. Also, they have added some solutions to limit such consumption. Figure 12 presents the percentages of consumption of the previous category before and during COVID-19 and different procedures of policies towards this crisis [35].

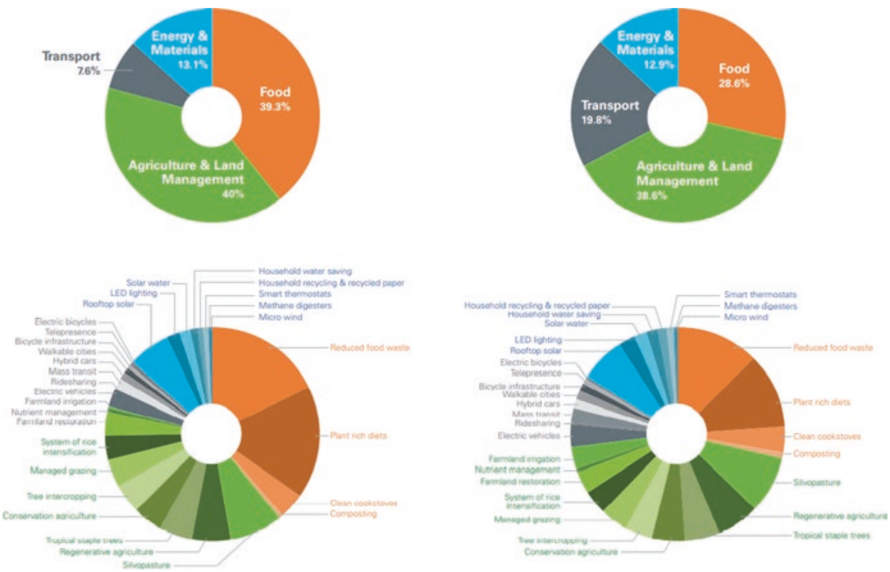


Fig. 12 Highest categories emitting GHG and ways to limit them before and in the age of COVID 19

6 Humans' Behaviour and Their Daily Activity

During COVID-19 pandemic, humans' behaviours have changed and consequently have affected the resilience of the city [36]. Residents have been affected by stress, illness, loss of jobs, inequality, and social exclusion. Unfortunately, these threats and risks have affected their daily attitudes, which some were mainly towards a better lifestyle, but the majority have been affected badly with a high risk of health records [37, 38].

6.1 Case Studies and Assessment

A group of different residents (100 people, as a first sample group of the first phase – a pilot study) with variable work backgrounds and ages have been selected to answer a certain questionnaire that indicates their daily activity consumption after COVID-19. Tested categories have been divided into five categories: (a) electricity consumption, (b) recycling, (c) travel, (d) food, and (e) usage pattern. The questionnaire was sent to the selected category of different countries, mainly all developing countries (Egypt, UAE, and Kuwait). These countries were selected due to the availability of data and their difference in population rates. However, phase two will be conducted on a sample of 1000 people to be pursued in separate research.

6.2 Calculation of Carbon Emissions That Resulted from Daily Activities

To assess the selected case studies, a questionnaire has been developed and conducted among the selected categories. It seems that none of the interviewed people is aware of the existence of the US Carbon Emissions Calculator, which is developed by the US Environmental protection agency (US-EPA), or even aware of any similar applications that test lifestyle, annual travel distance, air flights, number of people in the house, type of household and energy consumption. Afterward, all the gathered data were re-inserted into a US calculator to obtain real shocking results. Figure 13 illustrates the different categories covered in the questionnaire.

7 Results and Discussions

The major results showed that most of the population contain three members in a family, live in an apartment, use electricity as the main fuel type, get around using train or metro depending on the country, own a car, cut more than 10,000 km/year, fly less than 6000 km, eat meat and fish as main dishes daily, sometimes buy local

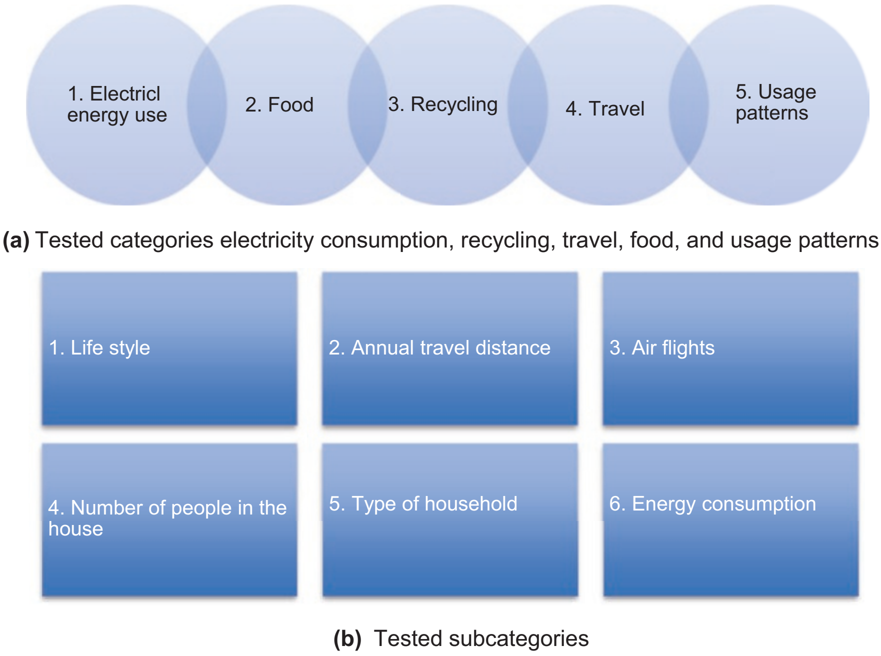


Fig. 13 Categories and sub-categories of selected population. (Image source: Developed by authors). (**a**) Tested categories such as electricity consumption, recycling, travel, food, and usage patterns. (**b**) Tested subcategories

products and deal with environmentally responsible companies, and almost eat once a week out. The assessment and questionnaire results are presented in Figs. 14, 15, and 16.

7.1 Carbon Emitted from Human Activities by Virtue of the US Carbon Calculator

Results also show that citizens in developing countries should take a faster and serious action towards the pattern of energy and resource consumption and raise awareness for these simulators so that citizens could be familiar with their usage. The previous statistics show that the carbon dioxide (CO_2) emissions per year amount to 23.7 tons, which is twice the rate of the UK Average Footprint – estimated at 9.5 tones [39]. The highest CO_2 emissions resulted from cars at a percentage of 59% followed by electricity at 22%, total flights' travel at 6%, and food at 13%. Results of carbon footprint from the pilot study compared with that in the UK footprint are shown in Fig. 15, while the footprint distribution is presented in Fig. 16.

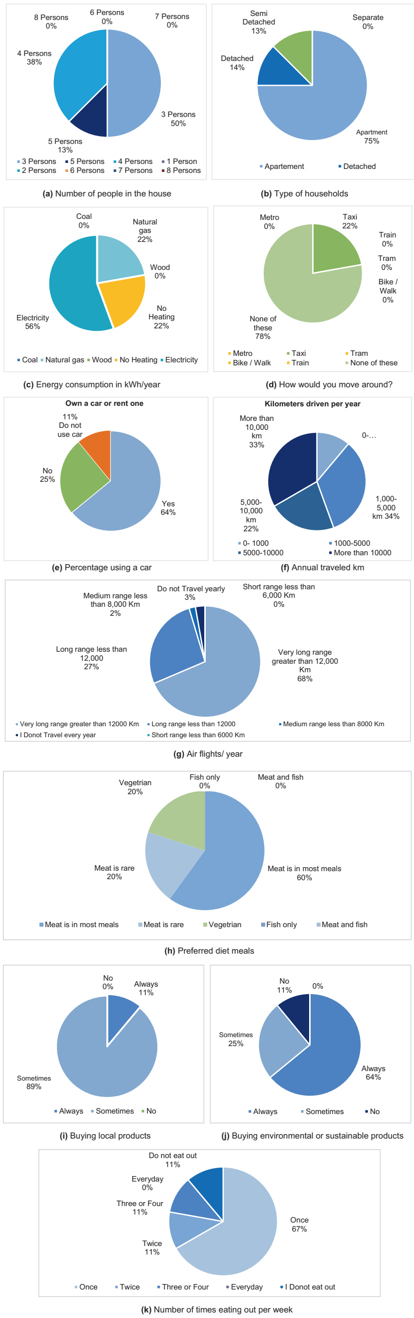


Fig. 14 Questionnaire results presenting the five categories. (Image source: Developed by authors) (**a**) Number of people in the house (**b**) Type of households (**c**) Energy consumption in kWh/year (**d**) How would you move around? (**e**) Percentage using a car (**f**) Annual travelled km (**g**) Air flights/year (**h**) Preferred diet meals (**i**) Buying local products (**j**) Buying environmental or sustainable products (**k**) Number of times eating out per week

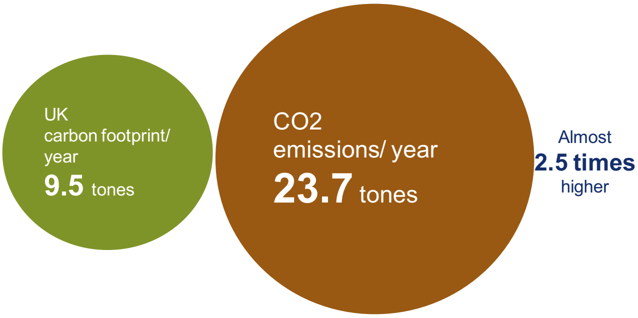


Fig. 15 Carbon emissions from yearly activities compared with UK Carbon Footprint. (Image source: Developed by authors)

Fig. 16 Footprint distribution based on carbon calculator. (Image source: https://footprint.wwf.org.uk/#/)

8 Discussions

It is clear from the assessment that 80% of citizens who responded to the questionnaire were not aware of the existence of carbon emissions calculator, while the other 20% do not have the actual time to use them. Although its importance is well known for all, human daily activities directly affect climate change and raise the spread of different infections. Hence, immediate actions must be taken by governments, local authorities, and all stakeholders to raise awareness and limit greenhouse gas emissions. The results are summarized in Fig. 17.

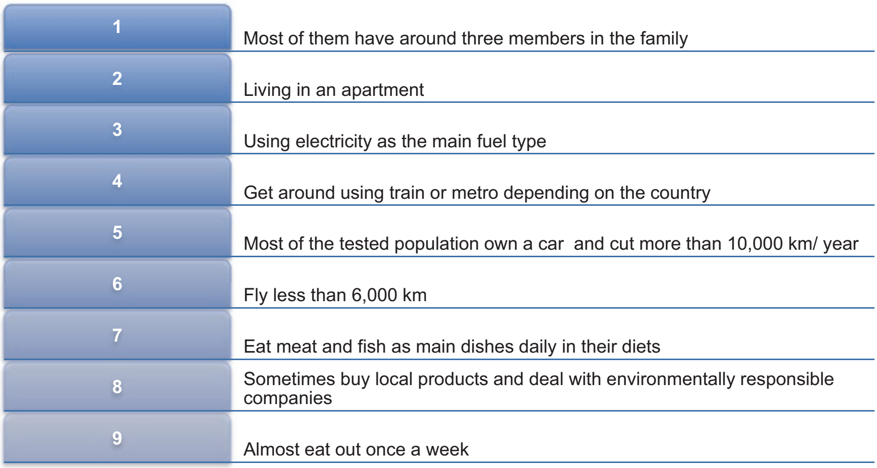


Fig. 17 Summary of the questionnaire results. (Image source: Developed by authors)

9 Conclusions and Recommended Solutions

Human daily activities and behaviours directly affect the sudden rise of GHG emissions which led to severe climate change impacts, such as air pollution, temperature raises, and the spread of diseases such as COVID-19. This relationship is considered a closed circuit, where the three influencing impacts (air pollution, temperature rise, and spread of diseases) affect each other; hence, actions should be taken simultaneously to limit their harmful impact on the surrounding environment. The analysis revealed that COVID-19 has impacted social, economic, and environmental pillars of the selected countries as social connections have been reduced by almost 80%, which resulted in downturn within the local economy, and delayed research addressing environmental challenges.

There is an urgency to address human behaviour in the age of COVID-19 as discussed in the study. A study was conducted among three countries to address threats and risks linked to climate change. Humans are considered one of the main key factors causing climate change either directly or indirectly, which immensely impacts humans' health. With the existence of COVID-19 and its stress impact, some people tend to eat unhealthy food, travel away many times through the year, and move away with their cars instead of using public transport, and others tend to switch on all electrical sources to feel secure and to eliminate depression. All these actions were done to enhance their moods and get over their panic feeling of getting sick or isolated.

The study revealed that these actions have led to high amount of CO_2 emissions accounting for 23.7 tons/year. This is estimated to be 2.5 times higher than that of UK's emissions (9 tons/year), where the highest emissions are from transportation means, mainly cars (59%), and the lowest emissions are due to the total flights' number/year (6%). Such carbon emissions are roughly considered the weight of the three Savannah elephants affecting climate change deeply and leading to the spreading of other diseases. For limiting these emissions, steps to attain a livable and resilient community should be implemented.

Moreover, the study suggests the following recommendations which could assist in mitigating these emissions:

- Eat local sustainable sources so that food and its emissions, due to international transportation, are reduced.
- Eat less meat and dairy (these are major causes of GHG emissions; beef, and palm oil production are considered amongst the largest contributions of pollution due to deforestation),
- Eat different crop types.
- Switch energy providers: natural gas, electricity, or other forms of heating fuel.
- Embrace new technologies (smart technology and sensors to manage lights and powers).
- Use public transport, but if you must use a car, follow the following tips:
  - Remove extra weight from your car and correct air pressure in tires.
  - Drive slowly (these simple tips will improve fuel consumption by an average of 15–25%.
  - Cycle local trips or journeys to consume no fuel, enhance health, and boost mood.
  - Buy one expensive car and then purchase another secondhand one (i.e., valuable products, inexpensive process, affordable, serving the community, and boosting the economy).

References

1. United Nations. (2022). *Secretary-General's video message to the Petersburg Dialogue*. [Online] Available at: https://www.un.org/sg/en/content/sg/statement/2022-07-18/secretary-generals-video-message-the-petersberg-dialogue/. (Accessed 19 June 2022).
2. Swim, J. K., Clayton, S., & Howard, G. S. (2011). Human behavioral contributions to climate change. *American Psychologist, 66*(4), 251–264. https://doi.org/10.1037/a0023472. PMID: 21553951. (Accessed 19 June 2022).
3. IEA, World Energy Outlook. (2017). *A world in transformation*. International Energy Agency. Retrieved 21 August 2023, from https://www.iea.org/reports/world-energy-outlook-2017
4. Food and Agriculture Organization of the United Nations. (2015). *Climate change and food security: Risks and responses*. [PDF] Available at: https://www.fao.org/3/i5188e/i5188e (Accessed 19 June 2022).
5. Eyring, V., Gillett, N. P., Rao, K. M. A., Barimalala, R., Parrillo, M. B., Bellouin, N., Cassou, C., Durack, P. J., Kosaka, Y., McGregor, S., Min, S., Morgenstern, O., & Sun, Y. (2021). Human influence on the climate system. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate change 2021: The physical science basis. Contribution of Working Group I to the sixth assessment report of the Intergovernmental Panel on Climate Change* (pp. 423–552). Cambridge University Press. https://doi.org/10.1017/9781009157896.005

6. IPCC. (2023). Chapter 3: Human Influence on the climate system. In *IPCC sixth assessment report Working Group 1: The physical science basis, Intergovernmental Panel on climate Change*. Retrieved 21 August 2023, from https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-3/
7. Page, N. C., & Page, M. (2014). Climate change: time to do something different. *Frontiers in Psychology, 5*. https://doi.org/10.3389/fpsyg.2014.01294. [Online] Available at: https://www.frontiersin.org/articles/10.3389/fpsyg.2014.01294/full (Accessed on 19 June 2022).
8. United States Environmental Protection Agency. (2020). *An overview of greenhouse gases*. [Online] Available at https://www.epa.gov/ghgemissions/overview. (Accessed on 19 June 2022).
9. Nielsen, K. S., Clayton, S., Stern, P. C., & Dietz, T. (2020). *How psychology can limit climate change.* [Online] Available at: How psychology can help limit climate change - PubMed (nih.gov) (Accessed on 19 June 2022).
10. European Commission. (2020). *Causes of climate change*. [Online] Available at Causes of climate change (Europa. eu) (accessed on 19 June 2022).
11. USGS. (2022). *How can climate change affect natural disasters*? USGS. [Online] Available at: How can climate change affect natural disasters? | U.S. Geological Survey (usgs.gov) (Accessed on 19 June 2022).
12. Celik, S. (2020). The effects of climate change on human behaviors. In S. Fahad et al. (Eds.), *Environment, climate, plant and vegetation growth*. Springer. [Online] Available at: https://link.springer.com/chapter/10.1007/978-3-030-49732-3_22 (Accessed on 19 June 2022).
13. Sobkow, A., et al. (2020). Worry, risk perception, and controllability predict intentions toward COVID-19 preventive behaviors. *Frontiers in Psychology, 11*, 582720. https://doi.org/10.3389/fpsyg.2020.582720. [Online] Available at: Worry, Risk Perception, and Controllability Predict Intentions toward COVID-19 Preventive Behaviors - PMC (nih.gov) (Accessed on 19 June 2022).
14. Pan American Health Organization. (2000). *Principles of disaster mitigation in health facilities: Chapter 1 – Disaster and hospitals: Background (nzdl.org) [E-book]*. Available at: Principles of Disaster Mitigation.pdf (eird.org) (Accessed on 19 June 2022).
15. Cheng, R., & Li, Y. (2021). Effects of human behavior changes during the coronavirus disease (2019) (COVID-19) Pandemic on Influenza Spread in Hong Kong. *Clinical Infectious Diseases, 73*(5), e1142–e1150. https://doi.org/10.1093/cid/ciaa1818. PMID: 33277643; PMCID: PMC7799278 [online] Available at: https://pubmed.ncbi.nlm.nih.gov/33277643/ (Accessed on 19 June 2022).
16. Bruneau, M., et al. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra, 19*(4), 2575. https://doi.org/10.1193/1.1623497
17. UNISDR, WMO. (2007). *Disaster risk and resilience* [online]. Available at: https://www.un.org/en/development/desa/policy/untaskteam_undf/thinkpieces/3_disaster_risk_resilience.pdf
18. Proag, V. (2014). *The concept of vulnerability and resilience*. (Published book, pages 369-376) [online] Available at: https://www.researchgate.net/publication/270293079 (Accessed on 19 June 2022).
19. UN. (2022). *Addressing climate change through sport*. [Online] Available at: PB_128.pdf (un.org) (Accessed on 19 June 2022).
20. Psychological scientists speak. (2020). *Human behavior in the time of COVID-19: Learning from psychological science.* [Online] Available at: https://www.psychologicalscience.org/observer/human-behavior-in-the-time-of-covid-19 (Accessed on 3 July 2022).
21. Fiksel, J. (2003). Designing resilient, sustainable systems. *ACS Publications, 37*(23), 422A–5470A. https://doi.org/10.1021/es0344819
22. Rose, A., & Liao, S. (2005). Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. *Regional Science, 45*(1), 75–112. https://doi.org/10.1111/j.0022-4146.2005.00365.x

23. Wilson, A. (2020). *Resilience in a Pandemic* [Online] Available at: Resilience in a Pandemic – Resilient Design Institute (https://www.resilientdesign.org/resilience) (Accessed on 3 July 2022).
24. Cimellaro, G. P., Reinhorn, A. M., & Bruneau, M. (2010). Seismic resilience of health care facilities. *Structure and Infrastructure Engineering, 6*(1–2), 127–144. https://doi.org/10.1080/15732470802663847
25. Ranjan, E., & Abenayake, C. (2014). A study on community's perception on disaster resilience concept. *Procedia Economics and Finance, 18*, 88–94. https://doi.org/10.1016/S2212-5671(14)00917-4
26. Proag, V. (2014). Assessing and measuring resilience. *Procedia Economics and Finance, 18*, 222–229. https://doi.org/10.1016/S2212-5671(14)00934-4
27. Impact of Covid-19 on Human Behavior. (2021). *Habits and how should one tackle the problem? [PDF]*. Available at: https://ctconline.org/wp-content/uploads/pdf/2021/seminar-presentation/essay/I-03-Aliasgar-Imani.pdf (Accessed on 19 June 2022).
28. Segerstrom, S. C., & Miller, G. E. (2004). Psychological stress and the human immune system: a meta-analytic study of 30 years of inquiry. *Psychological Bulletin, 130*(4), 601–630. https://doi.org/10.1037/0033-2909.130.4.601. PMID: 15250815; PMCID: PMC1361287 [online]. Available at: https://www.ncbi.nlm.nih.gov/pmc/ articles/PMC1361287/ (Accessed on 22 June 2022).
29. Youth and COVID-19. (2020). *Response, recovery, and resilience, OECD Policy Responses to Coronavirus (COVID-19).* [Online] Available at: https://www.oecd.org/coronavirus/policy-responses/ youth-and-covid-19-response-recovery-and-resilience-c40e61c6/ (Accessed on 22 June 2022).
30. Zautra, A., Hall, J. S., & Murray, K. (2010). *Resilience: A new definition of health for people and communities. [Handbook of adult resilience]* (pp. 3–30). Guilford. Available at: https://www.researchgate.net/publication/232581337_Resilience._A_new_definition_of_health_for_people_and_communities/ (Accessed on 22 June 2022).
31. Chin, L., & Hysteria, P. (2022). *Manufactured COVID-19 "health crisis" pushes humanity, global society to total shutdown*. [Online] Available at: https://www.globalresearch.ca/page/10?p=0FebFeb6/ (Accessed on 22 June 2022).
32. OECD. (2020). *COVID-19 and the low-carbon transition: Impacts and possible policy responses.* [Online] Available at: https://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-low-carbon-transition-impacts-and-possible-policy-responses-749738fc/ (Accessed on 22 June 2022).
33. Ahmed, F., Ahmed, N., Pissarides, C., & Stiglitz, J. (2020). Why inequality could spread COVID-19. *The Lancet Public Health*, 5(5): e240. https://doi.org/10.1016/S2468-2667(20)30085-2. Pub 2020 Apr 2. PMID: 32247329; PMCID: PMC7270465. [Online] Available at: https://www.thelancet.com/journals/lanpub/article/PIIS2468-2667(20)30085-2/fulltext/ (Accessed on 22 June 2022).
34. Hu, Q., et al. (2021). Are there heterogeneous impacts of air pollution on mental health? *Frontiers in Public Health, 9*, 780022. https://doi.org/10.3389/fpubh.2021.780022. [Online] Available at: Are There Heterogeneous Impacts of Air Pollution on Mental Health? - PMC (nih.gov) (Accessed on 22 June 2022).
35. Buttrick, N. R., Heintzelman, S., & Oishi, S. (2017). Inequality and well-being. *Current Opinion in Psychology, 18*, 15–20. https://doi.org/10.1016/j.copsyc.2017.07.016. Epub 2017 July 18. PMID: 29221506. [Journal] Available at: https://www.researchgate.net/publication/318533065_Inequality_and_Well-Being (Accessed on 3 July 2022).
36. Demine, V. (2020). *Managing climate change risks with high quality, Low carbon portfolios.* [Online] Available at: https://www.morganstanley.com/ideas/climate-change-low-carbon-stock-investing/ (Accessed on 22 June 2022).
37. Hoang, A. T., et al. (2021). Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: Opportunities, challenges, and policy implications.

Energy Policy, 154, 112322. https://doi.org/10.1016/j.enpol.2021.112322. [Journal] Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8455103/ (Accessed on 22 June 2022).

38. Bavel, J. J. V., et al. (2020). Using social and behavioral science to support COVID-19 pandemic response. *Nature Human Behaviour, 4*(5), 460–471. https://doi.org/10.1038/s41562-020-0884-z. [Online] Available at: https://www.nature.com/articles/s41562-020-0884-z/ (Accessed on 26 June 2022).
39. Carbonindependent.org. (2022). *UK average footprint*. [Online] Available at: https://www.carbonindependent.org/23.html (Accessed 22 July 2022).

Correction to: Retrofitting of an Existing Building to Be a Sustainable, Vibrant, and Smart Building

Rana Samir, Lamyaa Gamal, Simone Prospero, Pietro Durantini, Chiara Cappucci, Giuseppe Muliere, Abdelrahman Mohamed, and Mohsen Aboulnaga

Correction to:
Chapter 49 in: A. Sayigh (ed.), *Mediterranean Architecture and the Green-Digital Transition*, Innovative Renewable Energy, https://doi.org/10.1007/978-3-031-33148-0_49

Owing to an oversight, Fig. 1 of this chapter was initially published with an error. The correct presentation has been given below.

The updated original version of this chapter can be found at
https://doi.org/10.1007/978-3-031-33148-0_49

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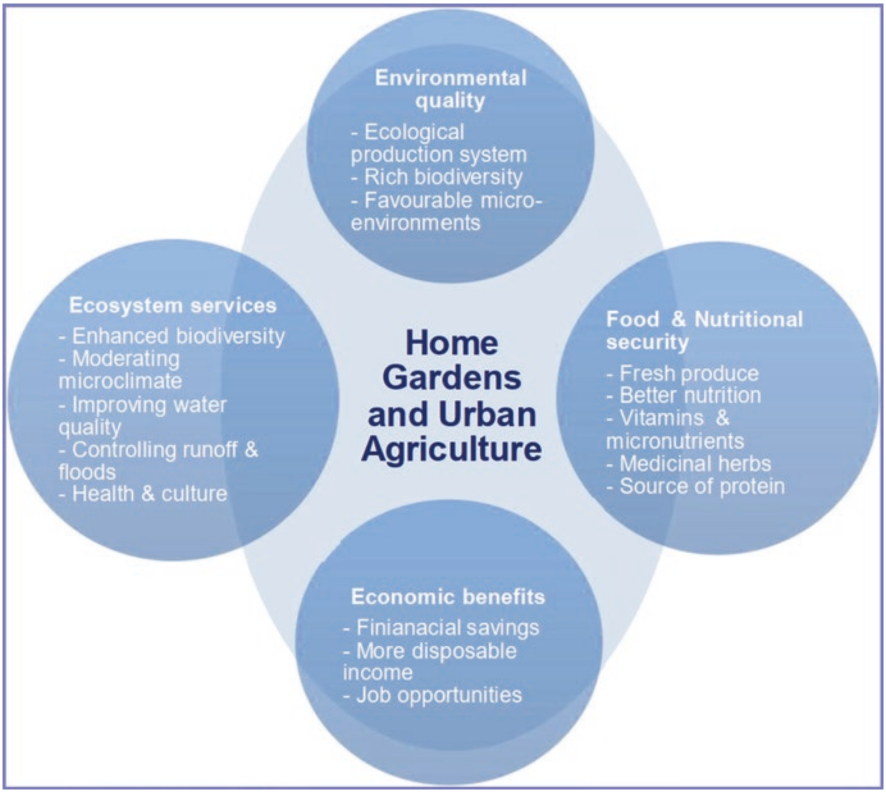

Fig. 1 Food, environmental, economic, and ecosystem service benefits of home gardens and urban agriculture. (Image Source: developed by authors after https://link.springer.com/article)

Index

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