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How can bioclimatic design foster diversification of low-energy building strategies in the next future? – design for long-term learning process in residential building

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Abstract. In recent years, Bioclimatic Design theory recognized users' adaptive behavior a central aspect to address low-energy and comfort in buildings. Users that once were considered passive receptors of comfort, now are provided with the tools to make themselves comfortable. This paper takes a step forward, recognizing that users can be passive, reactive and creative at the same time. People often adopt complex behavior, construct proper habits or create new ones, considering their own culture and values. In this scenario, Bioclimatic Design should identify new strategies to promote sustainable behavior among final users. In this sense, knowing how inhabitants learn from built environment is the first step in this direction. Designers must adopt people perspective and identify how they relate to the built environment, receive information and act pro-environmentally. Surrounded by architectures that enable learning processes, inhabitants will be able to ethically balance energy sufficiency measures as a trade-off between energy needs reduction, unpredictable events, and individual growth. Conclusions highlight that to continue differentiating energy strategies, architecture and technology should broaden user choices and allow natural development of pro-environmental attitudes based on deep ecological culture and wellbeing.

1. Introduction

Improving building performances means better architectural design. Reducing energy consumptions also depends on how inhabitants interact with their surroundings. While humans are highly adaptive beings to such an extent that they can hurt themselves [1], their hedonistic behavior can satisfy comfort needs at the expense of the environment. Therefore, encouraging ecological sensitivity is a crucial aspect to balance energy consumptions and comfort inside the built environment. In this sense, in a society in constant transformation towards sustainability, how will residential buildings support both individual growth and long-term pro-environmental behavior? This work is guided by this basic question to understand the end-user potential role in addressing sustainable concerns.

The present work is part of broader research that focuses on the impact of digital environmental information on learning processes in the architectural field. Therefore, it does not pretend to be exhaustive in its form, but to represent a theoretical input towards buildings with a more sustainable and human-centered lifecycle.

1.1. Structure of the paper
The paper consists of three different parts. The introductive part (section 2 and 3) describes the impact of people on building energy consumption and involves Bioclimatic Design theory in Low-Energy building strategies. Then, in the second part (from 4 to 7) users' long-term learning process is addressed, with a particular focus on sources of eco-information, usability and learnability of built environment following the example of cohousing design. Finally, in the last part (section 8) a case study is proposed, concluding with final comments (section 9).

2. Background
Buildings are one of the largest responsible for energy consumptions. Mostly it depends on how they are designed, informed, and used [2]. Understanding how people use buildings is an essential aspect for bridging the gap between design prediction and actual energy consumptions. Especially, pre-bound effects happen because households impose themselves to consume less in inefficient buildings [3]. For example, in Germany has been assessed a difference of 30% between 'real' consumption and predictions [4]. At the meantime, rebound effects happen when households live inside efficient buildings but tend to consume more [3]. In this case, efficient gains often lead to more consumption.

Involving or not end-users in energy problems depends on researchers' background and interpretation of sustainability. While some researchers suggest that constructing buildings less sensitive to people behavior is part of the solution [5], others argue that technology alone and stable conditions are unable to solve environmental concerns [6]. This paper considers that diversification of energy strategies allows people to build a more sustainable pro-environmental behavior based on greater engagement and a more shared ecological culture. To reduce the trend and achieve policy commitments, the whole society, architects and general inhabitants must be involved at the same level [2].

3. Importance of behavior in Low-Energy Strategies
In 2013 the International Energy Agency (IEA) recognized the diversification of Low-Energy building strategies, which include sufficiency, efficiency, and renewable energy measures [7]. While sufficiency address 'energy need' or the energy necessary for a specific end, like warming a room, cooking or lighting; efficiency is related to 'energy demand', which refers to the commercial energy required to run equipment and technological artifacts [8].

Considering Pricen (2005) sufficiency aims to 'enoughness' while efficiency tends to as much as possible with less. In other words, sufficiency address people behavior and foster energy needs reduction, focusing "on the switch, not the lamp" [9]. Fostering sufficiency measures enable inhabitant's choices towards a more ethical use of natural resources. Furthermore, sufficiency may indicate alternative design decisions, identifying configurations to implicitly guide users' behavior towards energy conservation. For example, one design decision could be collocating the stair core in the proximity of the entrance to discourage the use of elevators or making windows equally accessible and operable to people [10].

There is also an order in introducing energy measures. Sufficiency ones should come first to reduce energy needs before the introduction of more sophisticated technologies [11]. For instance, in the Mediterranean region, buildings should be designed first with the aim to capture and store solar energy, and only if required, to support the design with mechanical systems [12]. Consequently, sufficiency measures naturally connect with the central idea of Bioclimatic Design.

3.1. Defining Bioclimatic Design perspective
The IEA indicates Bioclimatic Design as sufficiency measures to minimize building consumptions [7]. It is a human-centered approach strongly correlated with regional climates and cultural differentiation. It claims that architecture should be linked to the local microclimate and aim for energy savings while maintaining comfort for the inhabitants. Considering the definition of the Architecture Institute of Japan (2010), it is an "architectural design that conforms to the nature of the area and can maintain the global

environment comfortable and pleasing to human beings" [13]. Moreover, at the center, there are user's consciousness and behavior, and architectures should allow interaction with buildings through 'life-size' technologies [13]. In other words, its main scope is to provide inhabitants robust and accessible technologies towards comfort balance and energy reduction, mostly deploying sufficiency measures.

4. From passive to creative behavior of inhabitants

How to provide comfort to people has conceptually changed over time. From the notion of 'shelter' against the exterior environment of the first theories [14] and "comfort as a right" [15], to the adaptive behavior of inhabitants, who are given the tools to adapt to reach thermal comfort goals [16].

Interest in adaptive comfort has grown exponentially since the 1990s (16), culminating in the PLEA-2009 Québec Manifesto, where it was recognized "the role of inhabitants as a key 'active' determinant of energy performance in 'passive' design, through adaptive opportunities" [17]. Particularly, it expressed various directives to improve performance in buildings. While *Directive 1* (Community context) express the necessity to adopt a multiscale approach to improve performance of building [15], *Directive 2* (Provision of adaptive opportunities) suggest realizing buildings with several adaptive opportunities. However, to support long-term learning attitudes providing end-users with different adapting tools does not guarantee ecological choices. Furthermore, it does not represent the complex nature of human behavior.

In real life context, the behavior is difficult to predict. While passive occupants do not alter their conduct, and 'adaptive' users react assuming the instruments given by designers, 'creative' inhabitants also encounter new meanings and alter space functions. In other words, according to Hill (2003), whose book helps to illustrate the nature of actions in architecture, people can learn new habits or modify the previous one considering newly acquired knowledge. Moreover, "passive, reactive and creative use can occur together" [18] (see 'figure 1'). For example, passive use can be encountered in a factory or during a wedding ceremony [18], but especially inside residential buildings, people "leaves doors open, generate body heat, keep tropical fish tanks and install plasma TV screens" [2]. Consequently, to support creative use, design strategies based on learning are needed.

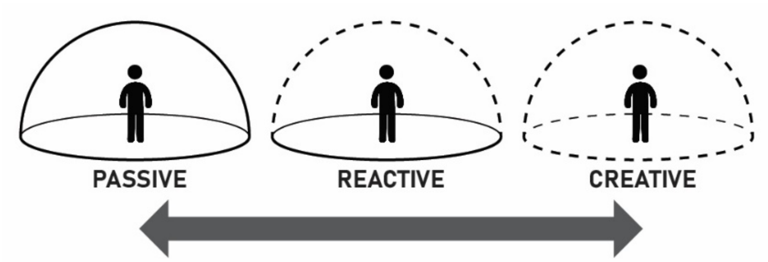

Figure 1. From passive to creative inhabitants' behavior occurring at the same time.

To address not only energy consumption issues but also long-term sustainability, people should learn gradually. Authors consider that short-term environmental attitudes based on extrinsic motivations do not last, and that sustainability requires a long-term commitment [19]. For instance, van der Linden (2015) concluded that long-term motivators are needed. In fact, in her case study, during a nationwide energy reduction competition among university students, electricity consumption effectively decreased over a month (the length of the event). However, about ten days after the experiment consumptions returned to normal [19]. Consequently, the case suggests that technology is not enough and that the learning process within the built environment should enrich the ecological culture of the whole society.

4.1. Learning process in Bioclimatic Design

From a Bioclimatic Design perspective learning process embrace the local environment, culture, and experience. In this respect, Guy and Farmer (2001) proposed to redefine sustainable architecture considering six interpretation, representing as many different sources of knowledge. The author distinguished the technic, centric, aesthetic, cultural, medical and the social perspective [20].

Even if the authors do not directly express it, it is inside the eco-cultural interpretation that Bioclimatic Design is collocated. As the authors illustrate, in such a concept of place human beings learn how to 'dwell' based on buildings that reflect the local cultural landscape and bioclimate [20]. In other words, comfort and energy reduction depends on learning from the local environment.

Outside strict categorization of sustainable design approaches, this paper will collocate Bioclimatic Design inside a broader interdisciplinary context taking inspiration from the holistic approach proposed by Moore and Karvonen (2008). In their study, Guy and Farmer's competing interpretations are utilized depending on different context and situation [21]. Therefore, Bioclimatic Design starting from the eco-cultural basis may adopt and collaborate with different 'sustainable interpreters' depending on where eco-information come from (see 'figure 3'). In this context, the next part illustrates how inhabitants' learning process may be supported by nature, architecture, technology, and community to 'bridge' the gaps between acquired information, concern and pro-environmental behavior.

5. From eco-information to pro-environmental behavior

Defining the process aimed at direct and indirect pro-environmental behavior is a complex task. Generally, people access information from a source, elaborate individual concern through learning, and then act pro-environmentally. However, over time environmental psychology and information studies have long studied the presence of 'behavioural gaps' and barriers between individuals and their conduct [22]. In 'figure 2' the information gap (gap 'a') indicates that individuals absorb not the totality of relevant information while the action gap (gap 'b') indicates that individual concern does not necessarily lead to environmental attitude due to barriers that hinder people positive responses [22]. Finally, eco-feedback represents the information proceeding from monitoring technologies and other digital tools.

In relation to the extent of the present work, external factors affecting actions and behavioral models aimed at explaining the knowledge-concern-action paradox [23], the latter widely studied in environmental psychology, will not be treated. Consequently, following the "figure 2" scheme, the primary sources of eco-information will be analyzed, proposing a general framework that identifies the role of architecture and technology concerning them.

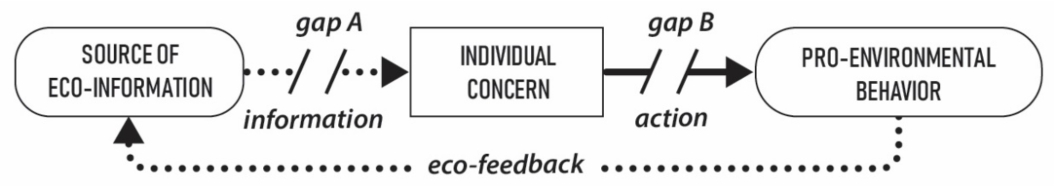

Figure 2. The process toward direct pro-environmental behavior.

6. Engaging end-user towards pro-environmental behavior

Sources of ecological information are the initial step towards pro-environmental behavior. Involving a broad context, social environment and interaction are the first dimensions that influence people behavior towards ecological actions [24]. Ian McHarg is considered a reference author in recognizing the positive (and negative) impact of collective choices towards the natural environment, preparing the foundation of what would then become landscape architecture [25]. Starting from his perspective, the community landscape theory of Mainzer and Luloff (2017) affirms that behavior, landscape, and local community form the basic interdisciplinary structure of pro-environmental actions at large scale [26].

Considering this field of interaction and the eco-cultural perspective adopted by Bioclimatic Design, a broad picture of eco-information, which can lead to a trend towards reducing consumption and inducing environmental behavior, has been identified. The 'dimensions' that constitute the framework are described in the points below.

6.1. The 'Bioregional and social' level

The bioregional and social level represents the background of the framework. On the one side, the Bioregion represents a combination of natural, ecological and biological elements [20]. Nature and ecology themselves represent a primary source of eco-information. Depending on the context, architectures generally integrated with living nature can produce respect for nature [27]. Besides, many researchers focused on biophilia recognize positive psychological effects on behavior [28]. To the other side, collocated at the same level, there is the society, where education, norms, and policies can support general environmental concern. Inside the 'bioregional and social' level it is possible to recognize three 'dimensions' of eco-information: the landscape, which is a combination of physical and cultural attributes; the community of people, different from general society; and the individual.

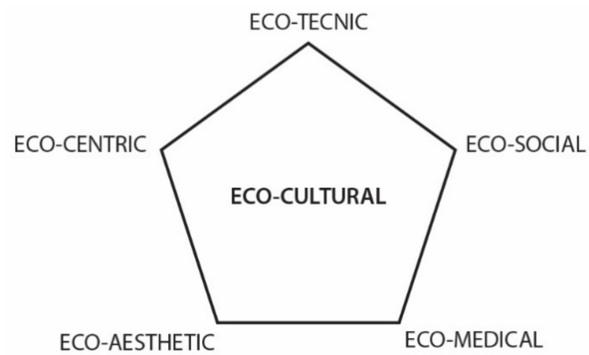

Figure 3. Eco-cultural interpretation as the central focus of a holistic approach to sustainable architecture.

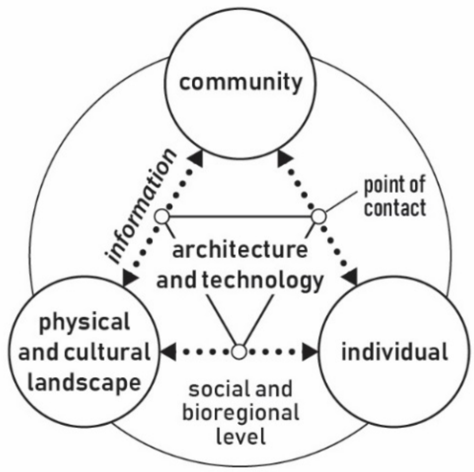

Figure 4. Architecture and technology should connect individual to community, landscape, and bioregion to foster learning processes.

6.1.1. The 'Landscape' dimension. Bioclimatic Design seeks to preserve cultural diversities connected to the local landscape, whose physical properties interact with the culture of the place [20]. The landscape physically reflects the values of the place and the environmental activities of the local society [26]. In other words, eco-information may come from the interaction between local settlements and the natural environment.

6.1.2. The 'Community' dimension. It represents the network of association constructed around individuals, and it is not referred to any precise scale [26]. Much of the information may come from the family or the clan that forms direct social connections [29], from co-workers or neighbors. Apart from social and cultural bound, seeing people acting positively may induce to imitation. For example, in a study related to household energy conservation in California, Nolan et al. (2008) demonstrated that even if people declared not to be influenced by neighborhood behavior, witnessing them resulted in manifested pro-environmental actions [30].

6.1.3. The 'Individual' dimension. Apart from being the one directly connected to pro-environmental actions, individual reflects cultural values, share environmental knowledge, and influence other people through indirect participation to environmental activities [22] or his direct behavior. Therefore, an individual is considered a potential source of eco-information.

7. Reducing behavioral gaps in the built environment

The framework described above individuates the basic condition that architecture, supported by technology, should establish points of contact between the various levels and different dimensions. In other words, not to constitute a barrier to the potential flow of eco-information. Furthermore, a typical example of a facility that has been designed to provide an ideal environment for interactions between the individual and community is cohousing [31]. Consequently, in the following text, to illustrate the design consequence of the proposed framework regarding social interaction, cohousing is described as the ideal solution.

7.1. Cohousing as ideal learning environment

Cohousing communities are residential settlements of generally 10-40 houses, where inhabitants intentionally agree to share living spaces and construct a group of individuals that support themselves towards wicked social aims like ecology, sustainability, poverty, and housing access. According to the Cohousing directory, currently there are 165 established communities in the US (with forming 140) [32]. Others nations with a consistent number or cohousing are Denmark, UK, and Australia [33][34]. Cohousing, like other grassroots initiatives such as ecovillages, low impact dwellings, and collaborative housing intend to foster interpersonal connections, social contact, and to promote pro-social and pro-environmental behavior at the same time [35]. Typically, cohousing considers at least 4 'design modalities' to foster pro-environmental behavior:

7.1.1. Usability and robustness of systems. The framework describes a bottom-up approach where end-users are co-producers of knowledge, along with 'design experts'. According to Manzini (2016), in a society gradually concerned with sustainable issues, general people are rediscovering the power of interaction and creative collaboration, also thanks to enhanced digital communication. Grassroots initiatives like cohousing represent this trend. In such complex environment, the distance between designers (interpreters) and creative communities is reduced, and design research, as well as its products, should be accessible to co-produce learning among different subjects [36]. Therefore, the built environment should be characterized by usability and robustness from the perspective of end-users. Usability aspects are commonly analyzed by HCI research and have been recently recognized in architectural design practice. According to Dalton et al. (2016), "[usability] is the capability of the building to be understood, learned and liked by the user, when used under specific conditions" [37]. Typical usability issues regarding mechanical systems are wrong labelling, inaccessibility, poor or complex interactions, which in facilities led by general public it may become frustrating [38].

7.1.2. Adaptive solutions and 'sense making' are considered together. To solve the complexity of energy reduction, the choice between several solutions should be supported by meaning. Interacting with people of the same community brings their daily experience so that to indicate the best adaptive solution, but also in defining its impact based on shared ecological values [36]. Diffused and locally generated knowledge is then part of daily life and constantly inform adaptive choices.

7.1.3. From individual to social learning. In this respect, Wilner et al. (2012) describe social learning as the process inside cohousing. Social learning occurs 'when we share our experiences, ideas, and environments with others' [39]. It is composed by a distinct moment of reflection: the *Single Loop Learning*, which addresses individual habits; the *Double Loop Learning* which is directed to intentions and considers interaction with others; and the *Triple Loop Learning*, which is dedicated to correct governance and procedures and is enabled in participative events. At the design level, each of those reflections is normally translated in physical spaces and scheduled inside the community.

7.1.4. Design for social connection and interaction. Cohousing design try to promote formal and informal encounters in shared spaces. In this sense, it generally analyses aspects like proximity of the housing units and their position considering neighboring houses, the features of the common room, shared pathways and surveillance given by the same members of the community [31]. The next text will present a case study of co-housing made by Stevenson et al. (2016), who illustrate the theoretical content exposed until this point.

8. The 'LILAC' case study

LILAC, the acronym of Low Impact Living Affordable Community, is a renowned urban-based cooperative project developed in Leeds UK, opened to residents in mid-2012. This low-carbon neighborhood consists in 20 straw-bale homes, plus 1 common house, welcoming 45 people of different ages (from 10 to 70 years old), occupation and family dimension (see 'figure 5'). During the design process, led by residents with the help of an energy consultant, general energy criteria were defined. Among them, there were low impact, future proof, comfortable, learning, easy to use and maintain, affordable, understandable and demonstrable [34]. To meet CSH level 4 and general needs of the community were installed PV array, mechanical ventilation units with heat recovery (MVHR), high-efficiency gas boilers with solar thermal water-heating system, among others (see 'table 1') [34].

Figure 5. View of the common building, the shared laundry on its right, the pond and other community spaces of LILAC neghbourhood.
(Source: https://makinglewes.org/2014/01/30/lilac-affordable-ecological-co-housing-project-leeds-uk/)

Figure 6. Interior view of the residence and typical operable windows with multiple openings.
(Source: http://www.bath.ac.uk/research/news/2013/12/12/straw-cuts-energy-bills-by-90/)

8.1. Learning co-production in LILAC

Conceptually, the project is a tentative to organize and anticipate what it might be a society free from fossil fuels, low-carbon and energetically managed with a bottom-up approach. Special effort has been dedicated to creating learning opportunity through extra redundancy and to give inhabitants the instruments to cope with unpredictable events.

In this sense, Stevenson et al. (2016) have recognized two kinds of redundancy in LILAC, which are intended to promote learning process: physical redundancy (technological and spatial) and social redundancy (from the local community) (see 'table 1'). According to the authors, redundancy is considered the component to 'translate adaptive capacity into action' [35].

First, spatial redundancy permits to create information exchange between individuals, community, visitors, and expert occasionally visiting the neighborhood. Furthermore, it gives people choices regarding their adaptive behavior. For example, houses configuration allows internal migration according to the moment of the day and season, thanks to multiple orientations of houses. At the meantime, the presence of exterior pond and gardens provide cool areas during summer seasons [35].

Second, technological redundancy gives inhabitants the possibility to select the best tools for their comfort, depending on previous experiences, renewable energy availability, technical malfunctions or misunderstandings. For instance, the learning process regarding microtechnology of the MVHR system has produced concerning. From the initial technician's advice of maintaining the unit always operative, inhabitants learned to switch it off alternating instead windows opening behavior and natural ventilation, considered healthier and more ecological. According to Stevenson et al., this multiple ventilation feature is given by the high operability of windows, which is not common in this kind of projects (see 'figure 6') [35]. Additionally, the researchers individuated 17 different adaptive behavioural patterns between MVHR and window systems depending on weather conditions (see 'figure 7') [35].

Table 1. Different kind of redundancy in support of social learning processes inside LILAC.

kinds of redundancy		
technological	**spatial**	**social (community)**
• Electricity from the national grid • Back up electric immersion heaters • PV and solar thermal panels • Wood stove (common house) • Separated water system (common house) • MVHR system • Multiple window openings	• Typical private houses • Common refuge • Common kitchen • Common living spaces • Common pantry • Separated laundry space • Central pond and garden • Central allotments (vegetable production)	• Inhabitants of various ages (different time availability) signing a common agreement • Selected 'maintenance task team' • Selected 'technology learners' • Mutual Home Ownership Society (MHOS)

Figure 7. Behavioural patterns between windows and mechanical ventilation system inside LILAC. (Source: Stevenson et al.)

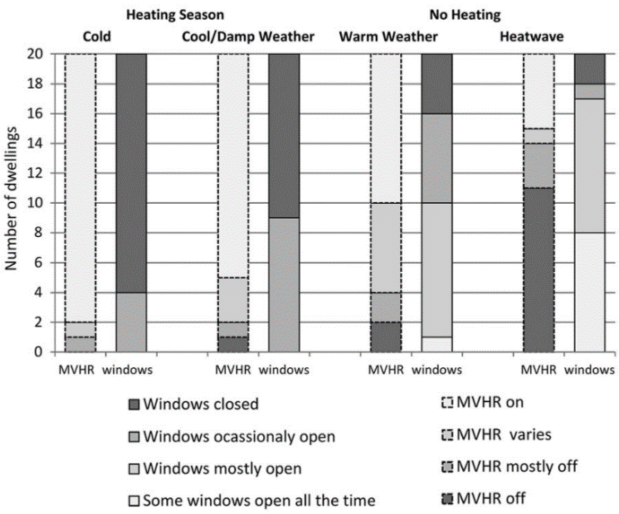

Table 2. Learning co-production and information flow inside LILAC.

Learning process of end-users	Modality of information flow
Individual learning (single loop)	• Trial and error
Peer-to-peer (interactive)	• Casual conversation • Researchers visits • Online tools (SNS and forums)
Collective (interactive and/or general redefinition of governance)	• Community notice board • General bimonthly meetings • Local and national events

Third, community redundancy is what permits different kinds of learning, from strictly individual to collective. As previously illustrated, different reflections are applied in order to promote social learning. For example, apart from individual learning (trial and error) guided by direct feedback, casual interactive conversation, and peer-to-peer learning may take place in the common laundry or at the doorstep. At the meanwhile more profound information and general participation regarding main governance can be performed, for example, during bimonthly meetings or local national events (see 'table 2'). In this scenario, among other figures, 'selected inhabitants' are dedicated to learn and access new technologies and to share their knowledge to other members, while the role of the 'maintenance task team' is to manage incidents and arrange the required repairs [35]. In other words, given that few systems (especially innovative and hi-tech) are readily accessible or 'smart' from the point of view of users, social learning is important for optimal use, but it may be not enough. Once the system is in place, it should not constitute a barrier to the learning process of inhabitants.

9. Discussion and concluding comments

People already know their impact on the natural environment, but there are barriers and gaps in the information process that hinder pro-environmental actions. In the next future, along with the efficiency of technological advances, Bioclimatic Design will be able to foster diversification allowing 'creative' inhabitants to find their path towards pro-environmental behavior through long-term learning processes and interaction with local community and landscape. In this scenario, the ideal example provided by ecological cohousing and the framework of source of eco-information indicate various design aspects to consider at the time of involving 'creative' end-users and communities. Among others: 1) Aiming at co-produced learning between individual and sources of eco-information; 2) Designing for social contact; 3) Multiple orientation of buildings; 4) Social and physical redundancy; 4) Extending human-building interaction outside private spaces; 5) Providing usable and robust technologies; 6) Differentiating learning times and participation; 7) Supporting adaptive solution with shared values.

To conclude, although cohousing initiatives are far from being easy to construct and manage, with issues regarding the up-scaling of their practices, they represent a clear example of bottom-up and long-term gradual approach towards a more diffused ecological culture. Furthermore, inside cohousing, digital tools play an essential role in shortening communication distances and triggering collective actions. But because of their inner organization, technological innovation must be carefully integrated into the built environment not to generate detachment between the individual and other significant sources of ecological information.

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