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Case Report

Implementing Regenerative Design Principles: A Refurbishment Case Study of the First Regenerative Building in Spain

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Abstract: The conventional building design and construction have detrimental impact onto the environment. With the current pace of development of the contemporary society, these issues cannot be fully addressed with the concept of sustainable design and construction, which is based on causing less harm to the environment. Thus, the regenerative concept is gaining relevance, as it is changing the construction paradigm toward the delivery of a human-centric environment, which, when coupled with the circular economy, aims to enable the natural environment to evolve. In order to have a more frequent delivery of regenerative buildings, it is necessary to broaden the knowledge on regenerative design, which is the objective of this paper. The aim is to investigate the design process, strategies, and technologies that are applied during the design and construction of a refurbished residential building, which is intended to be the first regenerative building in Spain, and is currently in the process of certification as per the Living Building Challenge (LBC) standard. Therefore, a literature review was performed, followed by a site visit of the case-study building. The research is organized according to the seven categories (petals) of the Living Building Challenge standard, and all 20 imperatives of the LBC are discussed. Additionally, the aspects of costs and project management are investigated. The findings point out the main design features and challenges toward the realization of regenerative refurbishment, in order to fully adhere to the demands of the LBC, and discusses their potential for a broader application in rural as well as urban settings. The analysis of the case-study design and construction can serve as a valuable insight to deliver future regenerative buildings and accelerate their implementation in the construction industry. This article is based upon the work of COST Action RESTORE CA16114, supported by COST (European Cooperation in Science and Technology).

Keywords: regenerative design; refurbishment; Living Building Challenge; passive solar design; circular economy; project management

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1. Introduction

The construction industry has been pointed out as one of the main contributors to environmental degradation and one of the main causes for climate change, with 50% resource depletion and 40% energy consumption [1]. Most buildings are designed and constructed in a conventional, unsustainable manner, neglecting the needs of the human and natural environment, while contributing nearly 40% to global energy consumption and approximately 36% of total carbon dioxide emissions [2].

The concept of sustainability has been propagated in the construction and architecture industries with vigor in the last couple of decades, aiming to fulfill the demands of the present society while also considering the needs of future generations. Its guiding principles are based on the unification of social, environmental, and economic aspects, and are oriented toward the design and construction of buildings that have a less negative impact on the environment [3]. However, the current pace of population rise, the need for new buildings, the ongoing consumption of resources, and the ongoing environmental degradation impose a need for a paradigm shift in the causal relation between the human and the natural world. Additionally, the Paris Agreement promulgated in the United Nations Framework Convention on Climate Change (UNFCCC) has set a target to limit the global average temperature to well below 2 °C above pre-industrial levels, and pursue a target of 1.5 °C, creating a demand for a new construction paradigm.

Further, approximately 40% of the European building stock hold was built before 1960, and 90% before 1990 [4], with a predicted average rate of refurbishment of 2–3% per year as part of the EU's Resource Efficiency agenda [5]. The *Directive 2010/31/EU of the European Parliament* defines "major renovation" as a renovation of a building where: (a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated; or (b) more than 25% of the surface of the building envelope undergoes renovation [6]. It has been noted [7] that sustainable improvements for retrofitting should consider the embodied energy and environmental impacts of material productions and refurbishment implementation. Different refurbishment tactics based on sustainability principles and multicriteria assessment schemes have been proposed for residential [8–10] and historical buildings [11]. Sustainable refurbishment is based on a multicriteria design, and several refurbishment assessment schemes have been established, including LEED [12], BREEAM [13], etc.

The relatively novel concept of regenerative buildings advocates going beyond sustainability. While sustainability consists in doing less harm to the environment, the regenerative concept means enabling social and ecological systems to maintain a healthy state and evolve [14]. Therefore, regenerative architecture is based on a holistic approach that supports the co-evolution of human and natural systems in a partnered and healthy relationship [14]. However, regenerative design principles are underutilized in the current architectural design practice.

The Living Building Challenge standard (LBC) was established by the International Living Future Institute and is a regenerative certifying scheme made out of 20 imperatives, organized in seven categories, or petals—Place, Water, Energy, Health+Happiness, Materials, Equity, and Beauty [15].The LBC strives to transform the conventional construction paradigm and approach to designing and constructing buildings toward having a positive impact on the greater community of life and the cultural fabric of our human communities [15]. The category Place consists of four imperatives—Limits to growth, Urban Agriculture, Habitat Exchange, and Car-Free Living; the category Water has one imperative—Net Positive Water; the category Energy consists of one imperative—Net Positive Energy; the category Health+Happiness consists of Civilized Environment, Healthy Interior Environment, and Biophilic Environment; the category Materials has five imperatives—Red List, Embodied Carbon Footprint, Responsible Industry, Living Economy Sourcing, and Net Positive Waste; the category Equity has four imperatives—Human Scale+Humane Places, Universal Access to Nature and Place, Equitable Investment and JUST Organizations; and the category Beauty has two imperatives—Beauty+Spirit and Inspiration+Education [15].

In the following sections, the methodology of research is presented, followed by the elaboration of the case-study building, the results of the analysis, and a discussion of the findings. Upon completion of the construction, the building will be monitored and assessed according to Living Building Challenge (LBC) standards and certified as the first regenerative building in Spain.

This case study provides significant insight into the design and construction process as well as the identification of obstacles and opportunities. The gained knowledge can be applied to future regenerative buildings.

2. Methodology

The aim of this paper is to investigate which design tactics, materials, and technologies are applied during the design and refurbishment of a residential building intended to be certified as the first regenerative building in Spain. The objective is to examine the design process as well as the underlying challenges that arise in the implementation of regenerative principles on the example of the case-study building. At first, a literature review was conducted in order to examine the Living Building Challenge standard for certification of regenerative buildings. This research is based on the Living Building Challenge 3.1 version for certification of regenerative buildings, the one that was valid at the time of the design and construction of the case-study building.

In order to achieve the research aims, a site visit and a semi-structured survey was conducted with the project manager and owner of the case-study building—the most knowledgeable and competent member of the project team, responsible for the execution of the project throughout its life-cycle, and the most respected stakeholder to describe the entire process. The project manager was directly involved during the project's life-cycle, from choosing the location to the building design, simulation, and analysis of performance, as well as the construction and certification. He organized the design team and the certification team that was involved during the design phase, providing guidance on the LBC standard implementation. Moreover, the project manager organized the construction team and the craftsmen that were involved in the production of specific detailing, in order for the building to comply with the LBC standard. The data and drawings were provided by the project team members for the GLP company [16]. The aforementioned activities occurred in a period of one month in the summer of 2018, followed by a technical data review provided by the GLP [16] company.

An interview, as a method, is considered as a popular tool for gathering data and has been extensively used in the research of the built environment. There are various types of interviews: structured, semi-structured, and unstructured [17]. The semi-structured interview provides a degree of freedom, creativity, and flexibility, thus enabling new ideas during the interview, which is why it is considered as an effective and convenient method for collecting qualitative scientific data [18].

The semi-structured interview is a form of dialogue between the participant and the researcher, based on a flexible interview protocol, supported by follow-up questions, as well as comments [19]. This type of method enables the collection of open-ended data, explores participant thoughts, feelings, and beliefs about a particular topic, and delves deeply into the topic of interest. The semi-structured survey demands a relational focus as well as practice in the skills of facilitation, such as: (1) determining the purpose and scope of the study; (2) identifying participants; (3) considering ethical issues; (4) planning logistical aspects; (5) developing the interview guide; (6) establishing trust and rapport; (7) conducting the interview; (8) memory and reflection; (9) analyzing the data; (10) demonstrating the trustworthiness of the research; and (11) presenting the findings in a paper or report [19].

The semi-structured survey established in this research consists of questions about design strategies, materials, and technologies that have been used in the design and construction for the refurbishment of an existing residential building, for fully achieving the demands of the LBC categories, such as: Place, Water, Energy, Health+Happiness, Materials, Equity, and Beauty. The questions in all seven categories are designed on the same principle, starting with the question "How does the regenerative refurbishment design address the category of...?", followed by unstructured sub-questions depending on the category itself and the specifics of the imperatives within the category. The questions investigate the qualitative and/or quantitative nature of the imperatives and their domain categories.

The findings of the study are organized and presented according to the seven petals, and all of the 20 imperatives of the LBC standard are discussed.

3. Case Study

Within the scope of this research, we present a case study of an existing residential building that is undergoing the process of regenerative refurbishment, with the goal of becoming the first regenerative building in Spain. The aim is to examine the design approach, tactics, and regenerative design strategies that are used in the delivery of a refurbished regenerative building. A case study, as a research method for investigating a certain problem, has been widely used, due to the potential it has to advance the research, practice, and education [20].

The project owner and manager is an expert in sustainable and regenerative certification, with a long-standing vision of constructing and certifying the first regenerative building in Spain. The building is located in the small village of Bresca, near La Pobla de Segur, Spain, located 42.31° N, 1.06° E. It is located 850 m above sea level, in the Mid-Pyrenees, in a climate classified as Cfb by Köppen and Geiger. In La Pobla de Segur, the average annual temperature is 12.3 °C, and the rainfall is around 701 mm per year. It is situated on top of a hill overlooking a nearby river and surrounding mountains, exposed to the sun throughout the year and to an upward breeze and wind, predominantly from the west side (Figure 1).

(a) (b)

Figure 1. View from the building toward the west and the nearby river (**a**) View from the building site, (**b**) View of the building site.

According to the statement of the project developer, the location for this regenerative refurbishment was chosen due to its beneficial orientation regarding sun exposure throughout the year, for passive solar heating, and the beneficial wind direction, which enabled natural ventilation and passive cooling.

The design of the case-study building started in January 2015 and lasted for 12 months. The preliminary design phase took 6 months, and the final design phase was completed in 6 months as well. The building license for the refurbishment of the existent building was obtained in March 2017. The construction works for the refurbishment started in April 2017, and the major part was completed in April 2019.

For obtaining the regenerative status, the building is currently registered for an LBC certification and started operating in September 2019. The performance monitoring period started in March 2020 and, according to the LBC protocol, is intended to last 1 year. The LBC certification is a performance-based certification. It therefore requires a 12-month performance period to demonstrate water and energy consumption. The certification process involves a certification audit by the Institute to verify the on-site compliance with all imperatives. In addition, the compliance with the imperatives is documented as part of the certification.

At the present time, the available performance data demonstrate that the case-study building is net positive in energy and water, but the LBC certification is done after a 12-month performance period. Additionally, data for air quality are gathered, and an educational material is developed and is intended to be published by the end of the performance monitoring period. In that regard, the actual certification will take place in the period of April–May 2021.

Moreover, the building sustainability aspects are confirmed, considering that in August 2020 the building was certified with the LEED Platinum with 92 points.

The building has an east-west disposition, thus enabling maximum south exposure of the longer façade. The main spaces of the house—the living room, the dining room, and the kitchen—are placed in the ground floor and have south orientation, while the stairs and the hallway are positioned on the north side, as well as the bathrooms. The building is attached by its east wall to a neighboring property. On the upper floor there are four bedrooms oriented toward the south and two bathrooms, one near the east and one near the west side. The building's floor plans are shown in Figure 2.

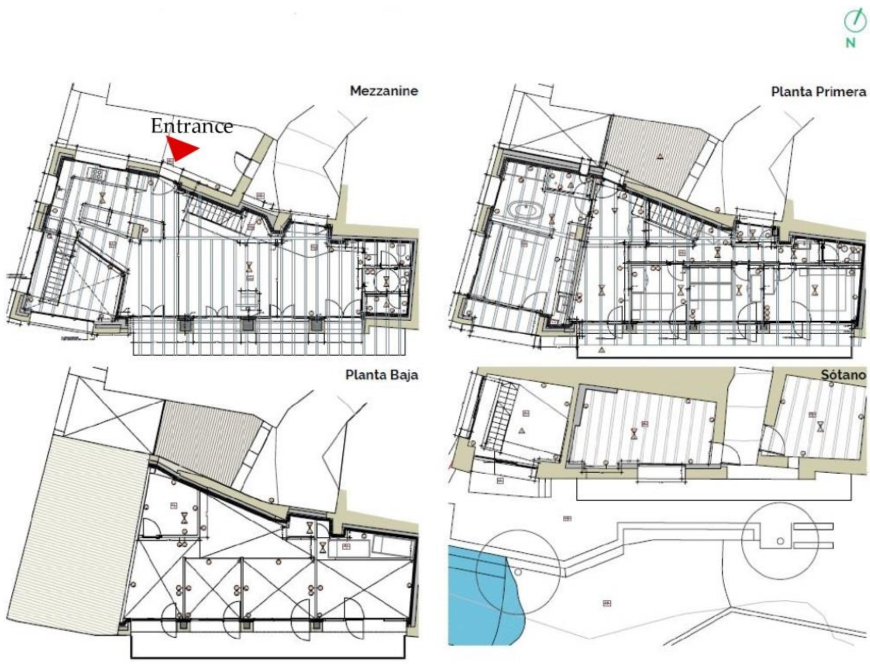


Figure 2. Case-study building's floor plans (provided by Emmanuel Pauwels and GLP, [16]).

From the internal layout of the building it is evident that spaces are arranged according to the principles of passive design, where the most commonly used spaces are oriented to the south, as an optimal orientation for passive solar heating, given the microclimatic context of the building's location. The utility spaces are placed on the north part of the building, thus decreasing the energy loss. As part of the refurbishment design and construction, the south-west part of the existing building has been torn down and a new extension has been built, where its northern part is a kitchen extension and the southern part a double height sunspace (Figures 3–5).

The passive solar design has been a topic of research of many researchers. In his book, Mazria [21] explains the empirical knowledge in passive design. More recent authors have explored optimal energy-saving solutions for a high-rise residential building where the glazing type, window-to-wall ratio, sun shading, and roof types can contribute to a total energy saving of 42% [22]. Moreover, the window-to-wall ratio, glazing type, and building orientation are investigated in relation to the energy performance for heating and cooling [23,24].

In the case-study building's design, a solar over-heating protection strategy is implemented. The overhang is used as a design tactic for blocking the summer sun and using the beneficial winter sun for passive solar heating. Deciduous plants and trees are intended to be planted on the south and the west side, which will be in accord with the aforementioned design strategy. Furthermore, this integration of plants deepens the connection of the building with the surrounding natural habitat, making it a part of the local bio-system. Additional plants on the south side will be kiwi and grape vines, which are planted near the building and will be used for local food production. Even though they do not shade the building, they act as a shade canopy for the users, providing a more pleasant use of the south courtyard during the summer period. The use of these plants is a nice example of an ecological design strategy called "stacking functions". This means that individual parts of the design perform multiple functions. Nature always stacks functions because it strives for efficiency. Kiwi and grape vines provide shade in summer, let the sun get through for passive solar gain in winter, provide food, and add a biophilic aspect to the building. Furthermore, the falling leaves will compost, thus improving the soil.

Figure 3. Exterior view of the case-study building.

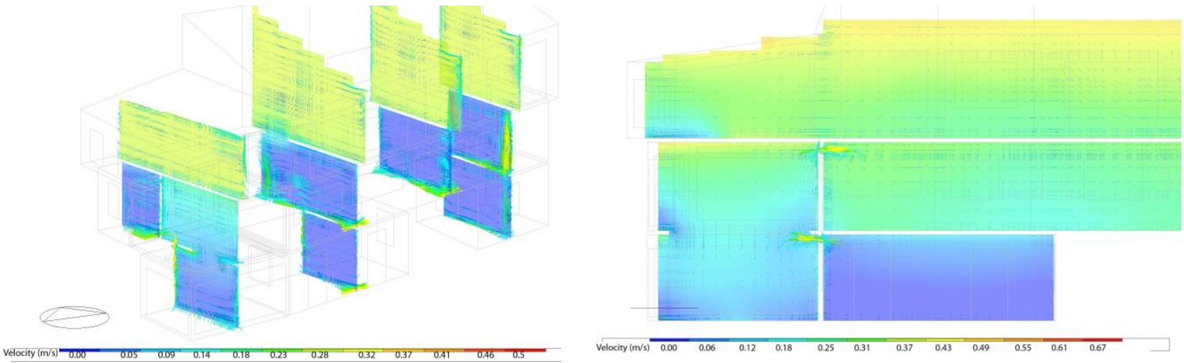
Figure 4. View of the south-facing façade of the case-study building.

The refurbishment project utilizes the concept of natural ventilation, which is defined by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) as "the introduction of outdoor air into a building driven by natural produced pressure differentials" [25]. For cooling aims, natural ventilation can be used through three means: cooling of the indoor air when the outdoor temperature is lower than the indoor temperature, cooling by convection; and cooling by evapotranspiration [26]. Natural ventilation can occur vertically, with an upward airflow, but also horizontally [25]. Studies have demonstrated that its efficiency is high in almost every climate condition [27]. The temperature drop inside the building, that can be caused by natural ventilation, is dependent on the outdoor temperature and wind speed, and it can vary by 4 °C up to 15 °C [28], thus having a positive impact on decreasing the cooling energy [29]. Regarding passive cooling methods, it is shown that passive cooling shelters, wind towers, and solar-assisted AC are able to decrease the indoor temperature as much as active cooling methods. However, they are not economically feasible [28]. Night-time ventilation consists in cooling the building structure by convective heat transfer [30]. The night ventilation and controlled ventilation are identified as the least expensive ones, while most expensive ones are: passive cooling shelter, PCM materials, green roof, etc. [28].

(**a**) (**b**)

Figure 5. The sunspace of the building: (**a**) Interior view of the sunspace, (**b**) Interior view of the gallery of the sunspace.

The case-study building is insulated from the inside, its thermal mass is therefore lowered, and the building is protected from overheating with the solar protection strategy. The natural ventilation strategy proves to be sufficient for providing comfortable indoor conditions in summer (Figure 6). At the same time, the controlled mechanical ventilation and high thermal insulation provide internal comfort in the winter period.



(**a**) Transversal cross-section (**b**) Longitudinal cross-section

Figure 6. Natural ventilation simulations (provided by Emmanuel Pauwels and GLP) [16]).

3.1. Place

How does the regenerative refurbishment design address the category of Place?

With the design of the building plot and by using vegetation from the area, the onsite landscape is intended to emulate the surrounding habitat in terms of existing biodiversity, nutrients, and similar aspects and satisfy the demand of the imperative Limits to Growth. For fulfilling the demands of the criteria Urban Agriculture, the concept of permaculture is used. A small edible forest is also planned, consisting of several layers: ground cover, herb layer, shrub layer, vine layer, and low-tree layer. A large percentage of the plants will be perennial, and the trees will provide food such as nuts and fruit. The area provided on-site for this purpose is approximately 30% of the floor area ratio, which is around 200 m^2. Regarding the Habitat Exchange criteria, the compensation for the built area is made by paying a non-governmental organization that takes care of a natural land in perpetuity.

For the fulfillment of the imperative Human-powered living, the owner has procured four electrical bikes. Moreover, there is a plan for commuting to the building by using public transportation, a train or an electric car, in order to be compliant with this imperative.

3.2. Water

How does the regenerative refurbishment design address the category of Water?

The water and sanitation system is designed by using a technology that is relatively easy to maintain and that enables complying with the LBC criteria.

The water system is based on harvesting rainwater in tanks, thus fully satisfying the water demand of the building. The rainwater is purified with a UV system and used for the bathrooms and the kitchen. The drinking water is filtered separately in a smaller tank which includes an active carbon filter and mineral stones to add minerals to the filtered, captured rainwater (Figure 7). The total indoor daily water consumption per person has been reduced to 50 liters, as opposed to the 150 liters consumed in a conventionally designed house. Some of the strategies implemented to reach this low level of consumption are: the use of composting toilets, low flow fixtures, efficient appliances, and a shower system which atomizes the water-pouring microdrops, which hydrate the skin far better than ordinary showers while saving water. The measured resulting consumption of the shower is 3.8 liters per minute. For optimization of the water use, a special system for micronizing the water flow is used, such as the Nebia shower, which uses 3–4 L/min (Figure 7c).

(**a**) Hot water tank (**b**) Rainwater storage (**c**) Nebia shower

Figure 7. Rainwater storage tanks and system.

The grey water from the kitchen is running through a grease filter before being sent to the constructed wetland for grey water recycling. This wetland consists of a 3 by 5 meter outdoor area containing gravel and vegetation, in which grey water from the showers, sinks, and kitchen is treated, and afterwards collected and stored so it can be used for irrigation.

In the bathrooms a special type of toilet seat was installed, which separates urine and faeces. The urine is collected in tanks and stored for 6 months in order to sterilize and to be used for the fertilization of the garden. The faeces are collected in a tank for a composting process of 1 to 2 years and then can be used as a fertilizer (Figure 8).

Figure 8. Composting tank.

The annual water consumption is shown in Table 1. The average daily occupancy is considered for four persons, and the annual consumption equals 63.145 liters.

Table 1. Water consumption.

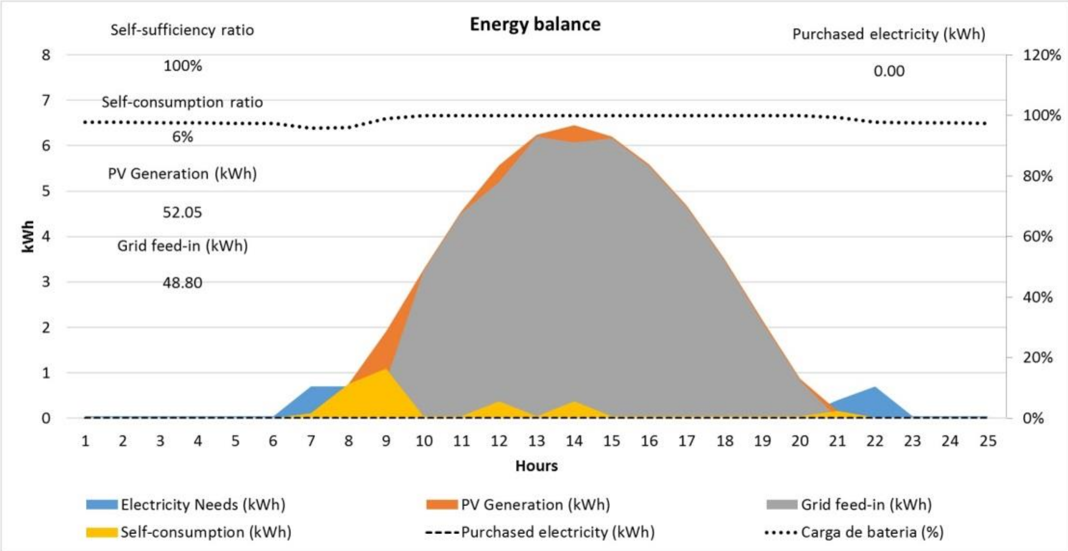
Elements	Flush/Flow Rate	Liters Per Person Per Day
Shower		19
Lavatory faucet	3.8 lpm	3.75
Kitchen faucet	2.5 lpm	12
Drinking water	6 lpm	2
Toilet	2 lpd	0
Dishwasher	0	3
Clotheswater (Washing machine)		3.5

3.3. Energy

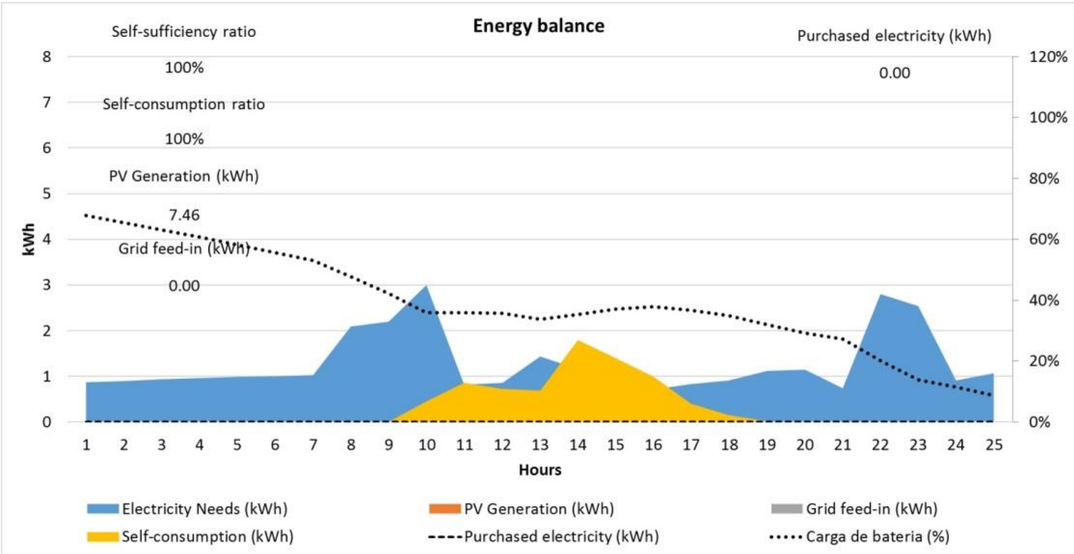
How does the regenerative refurbishment design address the category of Energy?

Considering the continuous technological progress, production efficiency, and implementation, the Photovoltaic (PV) technology has reduced its unit costs to roughly one third compared to 5 years ago [31]. The improved production technology has increased PV panel capacity and has become one of the key drivers for shifting toward a low carbon economy [32]. Additionally, it is considered that the PV sector may be a significant contributor to the circular economy [32].

For the energy simulation modeling and energy performance analysis of the refurbished building, the software tool EnergyPlus [33] was used. From the obtained results, it was calculated that 12 PV panels are needed with a total power of 3.96 kW in order to satisfy the building's energy demand and to achieve a net positive energy building (Figure 9).



(**a**) Energy balance on 11th of June.



(**b**) Energy balance on 27th of December.

Figure 9. Energy balance in summer and winter (provided by Emmanuel Pauwels and GLP [16]).

The successful integration of the PV panels on the building's roof has been a challenge, because of the local building codes, which prescribe that the clay tiles of the roof need to be visible. Additionally, the PV panels could not be placed in the building's plot because it is considered agricultural land, on which PV panels cannot be installed according to local regulations. However, a compromise was achieved with the local authorities by concluding that the building's roof is not visible from any local road, since the building is placed on top of a hill and the panels can be placed on the roof as long as they are not visible.

In order to store the energy, a 5 kW battery is installed in the building. The power of the battery is calculated to be sufficient to satisfy the peak energy demand of the building, for example when cooking and heating the building. Since the Spanish utility companies charge a fixed monthly cost for peak power and current Spanish building regulations require a connection to the grid with an installed capacity which equals the capacity of the PV installation, the design is focused on minimizing the size of the PV installation (3.95 kW). This way the monthly fixed cost charged can be limited while a peak power up to 7 kW will be provided by the battery.

The data from the performance period monitoring are shown in Table 2, and it can be concluded that there is a positive balance in spring and summer, while there is an additional demand for energy during the colder periods of the year. The building will produce 105.4% more energy than it consumes on an annual basis based on the current performance data. The information in the table for spring, summer, and autumn are actual numbers, while for winter the numbers are projected (based on the previous winter).

Table 2. Energy balance performance.

kWh/Day	Produced	Consumed	Energy Balance
Spring	20	13	7
Summer	25	7	18
Autumn	14	28	−15
Winter	14	21	7
avg	18.1	17.2	105.4%

Due to the aforementioned country-specific urban regulations, it could be stated that the integration of PV panels on the building's envelope for achieving a net positive energy building can be a challenging task.

For heating and cooling, a 9 kW heat pump, based on air-water exchange, was installed. The required capacity is actually 5 kW, but by installing a 9 kW heat pump, the equipment will run at a higher efficiency. For the distribution of hot/cold water, a radiant water system with polypropylene pipes in the new floor and in the existing walls was used. According to the energy performance simulation, it was concluded that cooling was not necessary in the summer period, as the natural ventilation design of the building and sun protection strategies on the windows prevent overheating. For the simulation, the comfort values of the LEED for Homes rating system [12] were used as reference.

3.4. Health+Happiness

How does the regenerative refurbishment design address the category of Health+Happiness?

By enabling natural ventilation and operable windows in each of the building's spaces, the imperative Civilized environment is fulfilled. The imperative Healthy Interior Environment needs to be assessed after the completion of the building's construction works. This imperative prescribes that the interior needs to be compliant with ASHRAE standards, which means that smoking is prohibited, there is a dedicated exhaust system from the kitchen and bathrooms, there is an outline for a cleaning protocol with products produced according to environmental standards, an Indoor Air Quality test needs to be performed 9 months after occupancy of the building, and the entryway system has to limit the entry of dirt.

For the criterion Biophilic environment, multiple design charrettes were held to explore the biophilic potential of the design. The number of design features in and around the building to create a biophilic environment is extensive and it would be beyond the scope of this article to list all of them. As an example, it is worth mentioning that the project relates to the surrounding context by the use of local materials on the exterior of the building, as well as in the interior. Another nice example of biophilic design is the integration of a "river" that runs through the kitchen (Figure 10). This consists of a small floor channel which channels the rainwater from the roof toward the rainwater capture tanks in the basement. The channel contains a filter material covered with colloidal silver combined with stones collected from the nearby river. The channel has a high biophilic value, since it looks like a Japanese Zen garden when dry, shows the movement and sound of running water when it rains, and contains rocks from the nearby river. It is also an element that provides human delight, celebrating our relationship with water and providing a visual verification of the flow of water from the roof to the capture tank. In addition, it contains a filter material to eliminate and to inactivate any possible bacteria and germs.

Figure 10. The Interior river channel.

The biophilic design was a continuous process, and everyone involved in both the design and construction actively participated, once the concept of biophilia was clearly briefed with them on multiple charrettes. Therefore, the biophilic design plan kept getting richer and richer as the project moved along. The river channel as a design aspect was proposed and agreed by the design team and the occupants, and therefore it represents a consensually agreed feature. Considering that there is a consensus on this design proposal, all of the participants in the project team agreed that it will add value to the project, its overall aims toward biophilic design, as well as its contribution to achieving the LBC certification. Moreover, for instance, after explaining the concept of biophilia to the tradesmen, they came up with the idea of incorporating animal motives into the interior finishes. Since the radiant wall areas are made of clay and straw, the clay could be sculpted. Together with the owner, they decided to represent some of the surrounding fauna.

3.5. Materials

How does the regenerative refurbishment design address the category of Materials?

The carbon emissions of the building's materials are considered throughout their life cycle, starting from the production of building materials, building construction, use, and demolition or recycling/reuse. Therefore, the materials used in construction are of the utmost importance.

For achieving the regenerative building imperatives, a passive design strategy was used for inserting wood fiber thermal insulation in the exterior walls, roof, and floor. The U-value of the roof is 0.125 W/m^{2}K, the exterior wall is 0.2 W/m^{2}K, the windows is 1.4 W/m^{2}K, and the floors is 0.17 W/m^{2}K.

Table 3 presents the materials used for construction of the external and internal walls. The following material layers have been used:

The exterior walls on the inner side have two types of rendering. The first rendering is a natural clay and sand plaster rendering. The second type is applied where radiant tubes are present, consisting of clay and straw (Figure 11). The construction of such a rendering requires skilled tradesmen in this project, and it was done by a local team specialized in these techniques. The use of a clay and straw finish is another example of stacking functions. This solution allows for the use of local materials, provides a visual and tactile result which is highly biophilic, allows the incorporation of art (in this case animal motives), provides a great thermal mass, and improves the radiant effect of the wall. In addition, the material is inexpensive. Behind the interior mortar, an air-tight barrier was inserted in the external walls, and it is expected to have an airtightness of between 1 and 3 air changes per hour (ach), which is to be confirmed by a blower door test performed near the end of construction.

Table 3. Construction elements.

External Wall 1	External Wall 2	Internal Wall	Floor Cover Basement	Roof	Glazing
Stone wall 20 cm, wood fiber wool–25 cm, air barrier, glass-fiber net, straw-clay mortar–4cm, polished clay finish.	Lime mortar, Lime primer, glass-fiber net, wood fiber wool–20 cm, ceramic blocks–20cm, straw-clay mortar–4 cm, polished clay finish.	Light-weight timber structure 12 cm filled with clay-straw mortar 4 cm	Ceramic tiles 1cm Cement screed–4 cm Concrete slab 12 cm over arched clay bricks, blown wood fiber wool–15 cm, wood fiber wool slabs–5cm	Roof clay tiles Wood fiber wool–35 cm	Existing part: Refurbished wood frames, double glazing argon filled New part: New FSC certified wood frames, double glazing, argon filled.
U = 0.2 W/m^{2}K	U = 0.2 W/m^{2}K	/	U = 0.17 W/m^{2}K	U = 0.125 W/m^{2}K	U = 1.4 W/m^{2}K

Figure 11. Rendering of an exterior wall.

The LBC standard defines a strict list of forbidden material compounds called the Red List. During the Design phase there were many difficulties with the selection of materials, as their compounds were difficult to obtain from the manufacturers, either because of patent issues, non-availability, or lack of cooperativeness. The design team had to compare each of the chosen construction materials with the Red List. Therefore, one of the central issues in the project was the selection of appropriate materials as demanded by the LBC standard.

As an example, the wooden windows had no information on formaldehydes in laminated wood from any Spanish provider. Additionally, another project issue was to obtain FSC certified wood, and after a long process of investigation, FSC-certified tropical wood was supplied by a window manufacturer in France. A material vetting manager has been assigned for this task since the beginning of the project. The amount of time invested in this vetting process was excessive and represents the most important cost, budget-wise, in the design process.

During the process of choosing materials, there were difficulties in obtaining the ingredients of the technical systems and equipment as well. Similarly, their compound list was often not available for different reasons, either due to patent issues, or because of the unwillingness of the materials or equipment producers to share their information.

The process of selecting, checking, and installing the materials and equipment usually started with a list of preferred materials established by the owner, followed by checking the ingredients' compliance with the Red List of the LBC by the Material Vetting Manager, who also searched for alternative solutions in case of non-compliance. Tradesmen such as an electrician and a plumber were involved in meetings prior to their involvement to identify all the materials they usually use, so they could be reviewed and validated. Most materials used in conventional buildings did not comply with the standard, and the tradesmen, once they understood the requirements, were able to help find compliant solutions. A good collaboration between the design team, the material manufacturer, and the tradesmen is critical for this material selection process to be successful.

The project management experienced difficulties during the tendering process regarding finding construction companies willing to take on this project. As traditional construction companies declined to provide an offer due to the lack of understanding of the project requirements, the project manager decided to set up a team of individual tradesmen and provide the training required.

A dedicated Construction Site Manager coordinated the day-by-day construction progress in close collaboration with the Material Vetting Manager.

By using local materials and re-using a lot of pre-existing materials in the building, the imperative Living economy sourcing was fulfilled. This imperative demands that 20% of the materials must come from within 500 km of the building's location, 30% from within 1000 km, 25% from within 5000 km, and 25% from anywhere, while the Consultants must come from within 2500 km of the location.

For the criterion Responsible Industry, the project used paint with a Declare label, and all of the new wood in the project is FSC-certified.

For the Net positive Waste, an inventory was made prior to the design phase to identify existing materials that could be reused. Furthermore, there is a waste separation and collection facility 15 km away from the project site. Construction waste was separated and transported to this facility.

The life-cycle assessment of the used construction materials and their environmental impact is examined using the software tool OneClick LCA [34]. At the end of the construction process the embodied carbon will be calculated, and it will offset buying carbon certificates. During the selection process of the materials, those with a lower carbon footprint were preferred.

3.6. Equity

How does the regenerative refurbishment design address the category of Equity?

The imperative Human scale and human places demands that 15% of the area is for parking, advertising billboards is prohibited, the maximum distance between façade openings is 30m, there is a need for a gathering place, etc. However, this indicator does not apply to residential buildings.

To comply with the imperative Universal access to nature and place, no fence will be placed on the property, thus not restricting any kind of movement.

In order to have an Equitable investment, for every euro of total project cost, half a cent is set aside for charity organizations dealing with forest protection.

Regarding the criterion JUST Organizations, the project management company, Green Living Projects, is the first company in Spain with a JUST certification.

3.7. Beauty

How does the regenerative refurbishment design address the category of Beauty?

This aspect is defined in the LBC as follows: "The project must meaningfully integrate public art and contain design features intended solely for human delight and celebration of culture, spirit, and place appropriate to the project's function".

Hence, special attention was paid to the building's design for achieving the imperative Beauty and Spirit. The building's integration with the surrounding environment is intended for human delight and celebration of the human relationship with nature. Considering the use of passive design principles and local materials, the building's design utilizes the unique characteristics of the "genius loci", as defined by Norberg-Schulz and its phenomenological approach to architecture [35,36]. Additionally, several social spaces have been planned for increasing social interaction and provide opportunities for rituals related to personal health as well as social well being. This includes: a yoga deck, a natural swimming pond, an outdoor wood-fired sauna, a round, Norwegian-style outdoor fireplace, or South American artisanal hammocks. One of the central spaces of this regenerative building is the sunspace, which is another example of stacked functions. This space, located on the south-west corner of the house, is a non-conditioned space with a large amount of glazing. It acts as a greenhouse collecting passive solar heat during winter which is then distributed to the rest of the house, a covered outdoor space providing a connection between indoor and outdoor space in summer, with views of the surrounding mountains, a space for social interaction, and a space for an indoor garden.

For the imperative Inspiration and education, the project team is planning to develop educational material about the design and operation of the project. Besides an educational website and an Operation and Maintenance manual, there will be a series of organized guided visits combined with educational workshops and stimulating conversations related to regenerative design. The project is a residential building, but it is designed in a flexible way so spaces can be transformed in workspaces, allowing visitors and guests to work remotely and enjoy the project as a rural office space.

3.8. Costs

The regenerative refurbishment of the case-study building is further analyzed from the aspect of costs as one of the most important aspects for a successful project completion.

Since the late 1970s, authors have stressed that the current linear economy, which is based on a continuous consumption of raw materials and global waste creation, is unsustainable in the long term [3]. Therefore, the concept of circular economy is proposed, based on the idea of closing material cycles and reforming the economy, where instead of throwing away used products and materials, a re-routing can take place to direct them into the right value chains, and in such a manner as to create a society with a healthy economy, inspired by nature and in balance with it [14]. In terms of the case study, a significant emphasis is given to the aspect of circular economy regarding the construction materials, most of which are natural or bio-based, reusable, or easily recyclable.

At the start of the regenerative building design process, an approximate budget was set by the building owner, as the main goal was to fulfill the LBC standard criteria, but also due to several cost uncertainties related to materials, construction costs, etc. During the project design phase, construction work estimations were made by an experienced estimator, but with references for more conventional construction practices and not for the intended unconventional materials and trades. This resulted in a significant difference between the estimated cost and the actual cost.

Although there was no detailed budget, cost was always adequately managed by the project team. For example, the large new glass doors in the sunspace have been installed with aluminum frame as opposed to a wood frame in order to lower the costs. Moreover, by refurbishing the frames of the existing windows, reducing the glazed area, and upgrading the thermal transmittance of the glazing, a cost reduction was obtained compared to replacing the existing window frames. Due to the use of natural materials, the material cost of the project was lowered, but this resulted in a higher labor cost due to the labor intensity of the work using more traditional techniques. It should be noted that the accreditation parameters were not compromised in the process of costs management and materials substitution.

A detailed cost analysis will be performed once the project is finalized. Based on the preliminary calculations, reaching Net Positive Energy is expected to be less expensive than a traditional built home over the Life Cycle of the case-study building. Reaching Net Zero Water is not expected to be lower in cost during all Life Cycle Basis due to the high cost of the tanks (rainwater capture, urine storage, composting tank) as well as the low cost of municipal potable water. However, as the village in which the house is located is experiencing shortages of water in the summer, being independent from the municipal water provides resilience to the building. Although a detailed cost–benefit analysis is not available yet, a preliminary conclusion from this research is that the upfront investment is higher compared to a conventional building due to the incorporation of additional systems in the design in order to make the refurbished building Net Energy and Water Positive.

4. Conclusions

This paper investigates the design and construction life-cycle phase for the refurbishment of a residential building, up until the certification process, which is out of the scope of this case-study analysis. This research examines the design principles, technologies, materials, solutions, craftsmen, and experience which have been applied during the design and construction of the case-study building, designed according to the LBC standard and currently in in the process of certification as the first regenerative building in Spain. The obtained results contribute to the body of knowledge on regenerative design, thus supporting a more frequent and successful delivery of regenerative buildings. From this research, several significant findings have been made.

A cohabitation of the human and natural world is possible with careful building design and its adjunct natural systems, comprising a cohabitant self-organizing system strongly related to its context. One of the largest obstacles in this regenerative refurbishment project was the selection and sourcing of materials that have a transparent compound list. In order to assist the regenerative design and to make it more efficient during the decision-making phase, it is necessary to advance the material compounds' transparency through reporting tools such as Declare. This will result in a significant decrease in time and money spent in the selection of materials, which is crucial for the delivery of regenerative projects.

Moreover, one of the concerns for a more frequent construction of regenerative building is the larger upfront costs. The additional plumbing systems, PV panels, and, especially, energy storage systems increases the investment costs. In order to solve this issue and stimulate the implementation of the regenerative concept, an incentive mechanism needs to be established by the governmental and local authorities. The project team tried to obtain subsidies or financing for these solutions, but so far it has not been successful.

Another obstacle for achieving the LBC imperatives can be the local construction regulations, which can reduce, disable, or even forbid the implementation of certain design aspects, materials, or technologies. Additionally, the energy and water policies can be an influencing factor for using the full potential of the regenerative concept as well as the site potential in this regard.

In order to implement the passive solar design principles and to fulfill the LBC imperatives, it is necessary to have a well-established and structured project management. Even more, it is of great importance to establish an integrated project team from the starting phase of the project until its completion, i.e., from the Initiation and Design phase to the Construction and Use phases. The project management needs to commence with a thorough observation of the context, accompanied by a visioning phase for determining the project's objectives, prior to a planning phase. Moreover, it is necessary to assign a project facilitator, who will support both the individual and the team mindset. The establishment of an integrated project team with clearly defined project goals enables the delivery of appropriate and timely solutions which otherwise could not be achieved due to a limited mindset, lack of knowledge, or even lack of will.

Therefore, the Design-Bid-Build process is not suitable for a project that demands a large number of specialists, engineers, and consultants with different profiles. A Design-Build contracting and project delivery process could be more suitable for the effective and efficient implementation of the regenerative design goals. Furthermore, cost analysis and a comparison with a traditional construction approach would be valuable for further research. Additionally, in such an analysis one must consider how the project contributed to the natural, human, social, and constructed capital, and not only to construction costs.

Furthermore, the design process needs to include certain design principles to make sure the outcome of the process is as cost-efficient as possible. One of these design principles, mentioned in this article, is the stacking of functions. The use of biophilia as a driver for design instead of an afterthought is another important principle that needs to be taken into consideration during the design process.

The implementation of the LBC standard in urban settings can be found challenging due to the aforementioned obstacles as well as the given urban planning regulations and conditions. However, it can be noted that due to the LBC criteria demand, the integration of the LBC design principles can substantially improve the quality of urban life. By fulfilling the Place petal, a substantial contribution can be made toward the improvement and preservation of biodiversity in the cities' neighborhoods, as well as stimulating urban agriculture and human-powered living as strategies to mitigate climate change and reduce urban heat islands effect and sustainability growth. Projects that operate within the water balance of a given place and climate can help rethink and redefine how people use water and wastewater, and how rainwater is harvested. These aspects are even more important for improving the resilience of the habitats, considering the climate change that is occurring, followed by extreme droughts or violent storms, on the other hand. The fulfilling of the criteria regarding Energy, PV, and Materials can be an issue that is challenged by local regulations. However, the advancement of those technologies and different refurbishment strategies can be considered to be more easily met in urban settings in the future. Considering that the LBC standard is in large part composed of qualitative criteria, the holistic integration of the project team, together with the certification and construction team, as well as the collaboration with the occupants, craftsmen, and even local municipalities, ensures the adequate and consensual fulfillment of the qualitative criteria of the LBC standard, thus delivering a regenerative building in its entirety.

The knowledge gained from the unique experience of regenerative design and the construction of the presented case-study could be applied in future regenerative buildings in order to increase their wider acceptance and implementation in contemporary construction practice.

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