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# Integrated Ecosystem Design: An Evaluation Model to Support the Choice of Eco-Compatible Technological Solutions for Residential Building

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**Abstract:** The technological components regarding building cladding are designed for ensuring thermo-hygrometric comfort conditions within habitable spaces and realising smart buildings. Often the solutions adopted are identified referring only to the characteristics of mechanical and energy materials without considering the ecological–environmental properties in an urban context. Thus, it is appropriate to choose technological components not only according to material type, but also ecological aspects pursued through presence and/or structured integration of natural elements. The technical-design forms based on “building–nature” integration allows, on one hand, the sustainable soil use with multiple benefits (ecosystem services) that natural systems produce, on the other hand, the identification of technological solutions sized referring environmental quality levels achieved through appropriate natural species use. In this way, it can be obtained lower buildings investment and maintenance costs, and greater energetic–environmental benefits. So, it is proposed an evaluation protocol for settlement transformation interventions structured considering environmental effects obtained with Nature-Based Solutions (NBSs) into the project. According to ecological–environmental quality level achieved with NBSs, the technological component is sized according to preliminary design parameters (noise reduction and solar irradiation degree) obtained through NBSs. The total performance level of technological solutions is expressed using Economic–Environmental Indicators. The protocol is tested on social housing case in Anagnina district of Rome (Italy).

**Keywords:** net-zero energy buildings projects; ecosystem services; eco-compatible technological solutions; nature-based actions; multicriteria decision analysis; Economic–Environmental indicators

## 1. Introduction

Since the beginning of the second half of the 20th century, the need to create a better quality of life for people in the cities of industrialised and non-European countries and the progressive increase in awareness of the increasingly rapid climate changes produced by human activities have led to the search for and implementation of settlement transformation interventions inspired by principles of environmental sustainability and based on an efficient use of available resources. [1]. Over time, the first shared definition of sustainability contained in the Brundtland Report for the World Commission on Environment and Development [2]: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs,” has been supplemented by numerous variations, extensions and specifications [3], which led to consider as its founding elements: economic and social development and environmental protection that in a long-term perspective are

closely related, interacting and interconnected, as well as essential to mutual subsistence. The concept of sustainable development is linked to ethical principles that look to long-term and intergenerational collective benefits also in terms of maintenance, inheritance, nonexclusion, fair distribution of the amount of natural, social and economic capital used and consumed in human activities [4].

From this point of view, the clear distinction between agricultural or forest areas and urbanised ones must be overcome, but these areas must be seen as open, interacting and continuous systems of varying intensity and consistency. According to European Environment Agency (EEA), the soil resource must be considered as an integrated system (land system) made of biophysical and human land subsystems [5]. Based on this point of view, the components of land use and land cover are elements of same process of landscape transformation. This unified vision of the land defines alternative ways of using it through an integrated territory planning in relation to ecosystem services produced by natural element.

As a result, since the 1980s, the design and construction of buildings in the most industrialised countries has intensified, using technologies and construction methods with a low environmental impact [6]. This has the aim of implementing design practices that can safeguard and enhance the existing environmental system through the management and conscious use of natural resources available useful for the construction of sustainable buildings and infrastructure. [7]. With reference to new processes of modification or recovery of urban land portions, or even to the enhancement and maintenance of the built environment, the implementation of techniques based on the optimal use of natural resources reduces greenhouse gas emissions into the atmosphere prolongs the life cycle and durability of building structures, as well as allows the achievement of better conditions of thermo-hygrometric comfort in the environments of the building [8].

On the basis of these considerations, in order to safeguard and reduce the consumption of natural resources in the production processes linked to settlement changes, a series of directives, recommendations and regulations have been produced and promulgated in Europe over the last twenty years aimed at identifying and establishing the minimum levels of energy performance to be guaranteed in buildings using appropriate construction technologies, both in the case of new construction and/or renovation of existing buildings [9–16]. Lastly, Directive 2018/844/EU, in amending Directives 2010/31/EU (concerning the definition of the energy performance characteristics of buildings) and 2012/27/EU (illustrating the methodology and calculation procedure aimed at verifying the energy efficiency of new buildings), defined some guidelines on energy efficiency that the Member States of the European Community must take into account in their intervention policies. This is in line with the European “Framework for Climate and Energy 2030” [17], which sets out three targets to be achieved by Member States by 2030:

- reduce greenhouse gas emissions by 40% compared to 1990 levels;
- to increase the share of energy consumption from renewable energy sources to at least 27%; and
- ensure energy savings of 27% by means of environmentally friendly measures.

From this perspective, the policy lines underpinning European development policies on energy efficiency direct Member States to implement projects aimed at constructing nearly zero energy buildings seen as “[...] very high energy performance buildings whose very low or almost zero energy demand should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced locally or nearby” [13,18]. Regarding Net-zero Energy Buildings Projects (NEBP) “[...] the balance of energy needs can be supplied with renewable energy technologies” [19].

With the aim of establishing the minimum performance levels to be guaranteed during the construction and management of building deemed to be energy efficient, also depending on any renewable energy sources on site, the European Union (2016) proposes a system of analysis of the energy performance of the building based on the principle of optimality of its characteristics in relation to costs (about the construction, routine and extraordinary maintenance and management). The use

of this system allows the determination of the level of energy performance, both with reference to buildings to be renovated and for new ones, in view of the lowest estimated cost during the own entire economic life cycle. This leads to the design and construction energy-efficient building systems, taking into account not only the cost items considered in the realisation phase of the technological solution considered, but also those relating to the energy consumption of the building and the intrinsic capacity to produce energy from renewable sources [20].

The experiments conducted at European-level (Germany, Finland and Spain), in which buildings have been built Energy Sustainable according to the model of the building with almost zero energy, are abundant [21]. These experiments are characterised by the execution of design actions, on a building scale and urban planning and design, aimed at reducing the emission of greenhouse gases into the atmosphere, and produce energy through energy supply systems derived from natural elements. In particular, “natural solutions, such as well-designed road vegetation, green roofs and walls that provide insulation and shade to buildings, contribute to reducing energy demand by limiting the need for heating and cooling and improving the energy performance of the building” [14].

The use of natural elements also as renewable energy sources for the sustainable development of the city defines urban forestry design practices. The European Union’s Forest Strategy [22] defines urban and/or peri-urban forestry interventions, such as “[ . . . ] multidisciplinary activities that encompass the design, planning, establishment and management of trees, woodlands and associated flora and open space, which is usually physically linked to form a mosaic of vegetation in or near built-up areas.” In particular, the execution of projects with the inclusion of new green spaces aims to raise the level of environmental quality (by reducing the concentration of pollutants in the air, lowering the sound pressure level at sources of noise pollution (e.g., high-speed roads), protecting the biotic component of the site and limiting land use), but also social and cultural, as well as bringing benefits to the new building in terms of energy savings and better liveability of their spaces [23].

The multiple effects generated by actions of urban environment qualification produced by the interaction between natural and built element, can also be expressed in terms of ecosystemic services, seen as multiple benefits evaluated according to the morphological and urban aspects of the area in which the intervention falls and the type of building to be built [24]. The types of services produced by the unitary “nature-building” system are divided into Regulating, Supporting, Provisioning and Cultural Services [25] on the basis of the objective set and the type of need to be met, both with regard to the reference context and the existing building and/or to be implemented. Each service is measurable by using appropriate environmental, economic and sociocultural performance indicators to express the multidimensional character of the integrated design on an ecosystemic basis conducted in the urban environment [26].

Compared to the growing interest in the field of energy containment and consumption of buildings and forestation applied as a means of intervention in the city, there is a lack of a unified strategy capable of encouraging a way of planning settlement transformation actions based on the integration of natural elements and built according to the production of services useful for the development of the urbanised territory.

In order for a building to be energy efficient in terms of ecosystems, it is not sufficient that it meets the energy requirements defined by the regulations, but a design process is necessary in which the choices made in the different phases and at the different scales (from the layout in the lot to the construction details, the envelope solutions to the plant system and the layout of the internal environments to the choice of materials), have as their objective to ensure overall environmental comfort achieved through the introduction/conservation of forest elements useful to limit the use of nonrenewable energy sources and to reduce the degree of soil consumption. The complex interactions between man and the environment involve the search for integrated design solutions that take into account the complexity of the “environment–nature” system and overcome the limits set by the action by considering separately in a sectoral way the different aspects that characterise them.

Thus, in order to respond to these complex requirements, it is necessary to adopt an integrated approach to design, based on an operational programme that allows the project actions to be developed in an ecosystemic way. The final result of this multidisciplinary, multidimensional and multitemporal process is the elaboration of Integrated Ecosystem Projects (IEP) carried out taking into account the ecosystemic logic deriving from the integration between urban forestry and the construction of buildings.

Based on the ISO 52000:2017—Energy Performance of Buildings Overarching Standard EPBD [27], which cancels and replaces ISO/TR 16344:2012—Energy performance of buildings—Common terms, definitions and symbols for the overall energy performance rating and certification [28], and ISO 16346:2013—Energy performance of buildings—Assessment of overall energy performance [29], the methodologies that can be used to measure the energy performance characteristics of buildings can be divided into two main categories of assessment procedures:

- (1) Calculated Energy Rating (CER);
- (2) Measured Rating (MR).

The CER provides the energy requirement according to the most usual climatic and management conditions related to the building spaces experienced by people. This implies the definition and use of parameters relating to lighting, ventilation, crowding, etc., in correspondence to the different thermal zones inside the building, which preserve the morphologies and technological–constructive characteristics of the project. The MR, instead, allows expression of energy performance estimating the annual energy consumption during the life cycle of the construction.

The CER and MR verify the performance of the building in consideration of the choices made on the types of construction solutions to be adopted in the design and construction phase from an energy point of view. In order to measure energy performance building according to project chooses on the type of technological solution to be made, some indicators can be taken into account during each evaluation performance methodology. As illustrated in many case studies in the literature [30–33], many indicators have been proposed to monitor and measure the energetic consumption of new constructions or of those already built. Quantifying normative performance of energy consumption in buildings began during the energy crisis in the 1970s [34]. With the purpose to secure and stabilise energy supply to be in line with the principles of sustainable development, the efforts to reduce national energy consumption need a building energy benchmark with a view to codify and standardise the corresponding level of energy efficiency through the use of Energy Performance Indicators (EPI). They track and compare different type of buildings (residential, commercial, for education), so to highlight trends of building's energy use for improving more efficient technological solutions and performance retrofits. Both at European and worldwide level, some research projects deal with energy performance indicators for building stocks. Among these, in a European context there were DATAMINE (2006–2008), TABULA (2009–2012) and EPISCOPE (2013–2016) projects; while within an international perspective the IEA Energy Indicators Project (from 2000 to today) and WEC-ADEME Energy Efficiency Policies and Indicators program (2008) exist. On the basis of these experiences, the most commonly used EPI for many building types pertain to energy, environmental quality and the economic–financial sector (in the Section 2.1 some EPI for energy measurement building are in Table 1). They feature the performance building level from design phase to management one. Among these some ones concern economic aspects of the construction. In particular, they regard the realisation and maintenance costs of the specific building work that it need to consider during its lifecycle. To integrate financial evaluations with other of different type (such as energetic ones) analytic methodologies were developed for it. On this line, the Life Cycle Cost (LCC) analysis allows identification of the total cost of construction or parts thereof over its lifetime, including the costs of planning, designing, acquiring, operating, maintaining and disposing of the work [35].

**Table 1.** Energy performance indicator set.

| a.<br>Key Sectors            | b.<br>Performance Indicators                                     | c.<br>Qualitative/Quantitative Valuation Variables   | d.<br>Design Guidelines   |
|------------------------------|--|--|---|
| Energy Sector                | Net energy demand (NED)  | Planimetric configuration of the Building;<br>Form Coefficient   | Quality of building and architectural choices   |
|                              | Primary Energy Consumption (PEC)                                 | Number and type of systems installed   | Use of an efficient plant system  |
|                              | Primary Energy Ratio (PER)                                       | Rate of energy that can be extracted from renewable sources  | Electricity generation strategy and type of fuels used  |
|                              | CO <sub>2</sub> emission   | CO <sub>2</sub> concentration in the atmosphere  | Use of energy sources with low environmental impact   |
| Environmental Quality Sector | Daylight Factor (DF)   | Number of hours of sunshine perceived during the months of the reference year;<br>Presence/absence of the shielding system | Use of shielding systems for the use of natural lighting  |
|                              | Visual Comfort   | Planimetric configuration of the building  | Planimetric layout of the building according to the Elio-thermal axis   |
|                              | Predictive Mean Vote (PMV)                                       | Level of thermal comfort perceived by a group of people in a given environment inside the building                         | Use of natural and/or artificial cooling/heating systems able to improve the thermo-hygrometric conditions inside the building's rooms                  |
|                              | Percentage People dissatisfied (PPD)                             | Number of people feeling too hot or too cold in the same room  |   |
| Economic-financial Sector    | Cost Optimal Level (COL)   | Estimate of the cost of construction and maintenance of the building   | Use of energy-efficient technological solutions at low cost of construction and maintenance   |
|                              | Financial convenience of investing in energy efficiency measures | Pay Back Period (PBP);<br>Rate of Return on Investment (ROI)   | Integrate the intervention of energy efficiency of the building with the design of environments to be used for services for residents and the community |

The proceeding section, which aimed to evaluate the building under multiple aspects (environmental, social, energetic and economic–financial), appears complicated due to huge number of variables to be considered and the difficulty to relate each other, also in the perspective of making choices for technological sustainable solutions for an optimal energetic building performance. The usual practices of design and work construction in energetic terms are principally on the basis of the fulfilment of regulatory limits on energy efficiency, and few times they take into account the effects and/or benefits that can also be expressed in the form of ecosystemic services deriving from the interaction between the tree elements around and the building structure in the process of carrying out the settlement transformation intervention.

In general terms, vegetation is attributed a fundamental role in the fight against climate change in relation to the capacity to store atmospheric CO<sub>2</sub>. The CO<sub>2</sub> absorption capacity depends both on the environmental conditions (temperature, light availability, etc.) and on the characteristics of the species (leaf surface, growth rates, etc.) and the individual tree (age, health status, etc.). In urban environments it is recognised that the presence of trees mitigates the “heat island” effect found in densely built areas (in these areas the temperatures can be 5–9 °C higher than in areas with lower building density) and has an insulating and windbreak effect on buildings with consequent savings on energy consumption and operating costs resulting from the lower need for cooling (through the use of air conditioning systems) in warmer periods (summer) and heating (through the use of heat production systems in winter). In other words, vegetation, because it can be considered among the passive systems that have effects on heating, cooling, shading and shielding to the wind, and therefore affects the quality and temperature of the indoor and outdoor air of buildings, is one of the factors to be taken into account in calculating the energy efficiency of buildings, as indicated by the European Commission. As well as helping to make cities cooler, healthier and more liveable, vegetation can contribute to the reduction of CO<sub>2</sub> in the atmosphere in relation to location, species, size and context conditions through

- (1) its absorption by stomatologic means and
- (2) inducing, with its presence, a saving in the energy consumption of buildings.

It should be kept in mind, however, that tree and shrub species in urban environments are particularly subject to functional stresses that affect their life span and the effectiveness of CO<sub>2</sub> absorption dictated by various factors such as pollution, footsteps, etc. Consequently, it is necessary to choose species that are resistant and suitable for the context in which they are to be inserted, to provide for their cyclical maintenance over time and for the possible replacement of sick or dead individuals in a short time.

In the literature, especially among American studies, there are some case studies that deal with the link between nature and built environment, with specific regard the Building Performance Capacity and Urban Forestry Ecosystem Services [36–38]. In particular, it is highlighted the beneficial effects generated by the presence of natural elements on the buildings. In terms of both increasing the health and well-being of residents', it increases the property value and improvement of environmental conditions in the area of the building. The specific benefit derived by natural element in relation to build system can be measured also with the use of apposite evaluation models. Their use allows appreciation of project solutions, both at the urban and building scales, in a holistic manner on the basis of the specific ecosystem service produced by forestry. But, a formal definition of building capacity within the urban forestry is lacking. In fact, there is currently a lack of integrated planning in urban areas only have limited capacity to deal with the urban forestry issue and its implications also at building scale under energetic point of view.

So, in order to be able to jointly consider energy and ecological–environmental aspects, the use of multicriteria approaches allows expression of the multiple effects that a settlement transformation intervention carried out in an integrated manner can generate both on the building and on the portion of the area immediately surrounding it. The evaluations on Integrated Ecosystem Projects must be able to consider the use of indicators referring both to the forestation and to the energy

performance characteristics of the technological solutions used to construct the building. The joint use of multiple indicators makes it possible to formulate evaluations in an ecosystemic key and to express the multidimensional character of settlement transformation projects including forestation and the construction of new building structures. Depending on the type of indicator chosen and the objective of encouraging the execution of integrated design practices, it is possible to build evaluation models based on multicriteria logic with which to solve complex decision-making systems. Models of this species are generally used in urban planning and design where it is specifically necessary to establish the optimal allocation of available financial resources between investment projects assessed according to sustainability principles [39,40], as in the case of urban forestation interventions [41–43] or the recovery and conservation of existing buildings [44] or to carry out interventions in public private partnerships [45].

In the light of these premises, a multicriteria approach is illustrated which is useful for carrying out evaluations aimed at favouring the execution of IEPs by integrated ecosystemic logics. In order to verify the applicability of the proposed approach, attention is focused on the assessment of the benefits generated by the integration between the forest and the built with regard to both the sizing of the technological solutions components considered for the construction of parts of a building (especially those of the outer shell of a facade) and the effects (environmental, social and economic–financial) produced by interventions in an integrated ecosystemic key. The use of this approach orients the design of the building organisation on the basis of ecosystem principles, taking into account aspects related to both the forestation and the intrinsic potential to produce services for residents and nonresidents, and the technological–constructive system that influences the energy performance of the construction.

In Section 2, by examining the main indicators used to assess the energy performance of the building and those used to express the benefits obtainable through forestation (Section 2.2), some common indicators are identified with which to make value judgments on projects carried out in an integrated ecosystemic key.

The use of these indicators is part of the process regarding a proposed multicriteria evaluation approach with reference to settlement transformation interventions that include forestation and construction of energy efficient buildings (Section 2.3). Section 3 describes the phases of the proposed multicriteria methodology about the case study considered. Finally, in Section 4 conclusions are reached and the potential for application of the proposed approach as well as future research perspectives are discussed.

## 2. Material and Methods

### 2.1. Premise

As already pointed out above, in order to be able to measure the multidimensional character of initiatives aimed at constructing new building structures and/or enhancing the existing ones by including in an integrated manner the conservation and/or insertion of forest elements in the intervention area according to integrated design principles that also produce effects in an ecosystem key (Integrated Ecosystem Projects), it is advisable to resort to the joint and/or disjointed use multiple indicators capable of expressing both the performance–energy qualities of the building and the effects that the forestation produces both on the territory and built environment.

According to Section 1, where only urban forestation interventions are involved, the indicators to be considered for assessing the intervention are mainly natural/environmental and are linked to the type of effect produced by the inclusion of natural elements.

In the case of Energy Sustainable Projects, on the other hand, the Key Performance Indicators used for evaluating the energy performance of buildings measure the thermo-hygrometric conditions of the building, the demand and level of consumption of energy from renewable sources, as well as the Cost Optimal Level according to the construction system and the technological components used to build the construction and the energy sources consumed during its life cycle.

When it comes to carrying out an intervention based on the integration of natural elements and built in an ecosystemic design logic, it is necessary to take into account multiple aspects (energy efficiency and urban forestry) considering together in their relations the different indicators of environmental, social and economic–financial type.

Among the indicators found in the literature to express the energy performance of the building and those used to measure the effects of forestry, some allow us to jointly express both the energy level of the building and the improvement of environmental quality conditions that define the exterior close to the building.

This is achieved by using appropriate evaluation methods to measure the indicators chosen for Integrated Ecosystem Projects in terms of quality and quantity. For example, by means of the indicative parameter, the concentration of CO<sub>2</sub> in the atmosphere can quantitatively express both the rate of carbon dioxide in the atmosphere of the natural environment surrounding the building and the performance characteristics of the technological components, as well as the quality of the Health Perception commensurate with the improvement in air quality due to forestation.

Thus, preferring the logic of integration between the natural and built systems, the set of indicators (Section 2.2) specific to measuring the energy system of the building and the effects of forestation are illustrated below.

From the comparison between the two sets, some (the most significant) common indicators for Integrated Ecosystem Projects (CO<sub>2</sub> Concentration, Green Spaces Interactions, Plant Biodiversity Level, Environmental Quality, Visual Comfort and Cost Optimal Level) are identified and illustrated, and the corresponding measurement methodologies are exposed.

Subsequently, the proposed multicriteria evaluation approach (Section 2.3) is illustrated. This approach allows the formulation of judgments of convenience on settlement transformation interventions developed in an integrated key.

This is done by using the indicators chosen from those present in the literature with which to jointly express the energy performance of the building and forestry through ecosystemic logics. It is necessary to clarify that indicators proposed for evaluating IEP (such as that in Table 2 in case study section) are oriented to express the multiple beneficial effects that can be generated by the interaction between green layout solutions and technological solutions for the building.

So, among possible indicators useful to evaluate IEP's effects, as well as in terms of technological component choice, some indicators are selected in order to measure the interactive implications between forestry project construction and their logical interdependencies.



**Table 2.** Urban forest indicator set.

| Target                         | Indicators Set Unit of Measurement  |  |   |  |  |   |   |
|--------------------------------|---|--|---|--|--|---|---|
|                                | Clark et al. (1997)   | Van Ondehoven et al. (2002)  | De Groot et al. (2010)  | Kenney et al. (2011)   | Dobbs et al. (2011)  | Koske et al. (2012)   | Barron S.et al. (2016)                                  |
|                                | Canopy Cover [m <sup>2</sup> green areas/m <sup>2</sup> area]                   | Cohesion and Coverage of Land Cover and Landscape Elements [Qualitative Scale] | Presence of Edible Plants and Animals [N° Species]                            | Relative Canopy Cover [m <sup>2</sup> green areas/m <sup>2</sup> area]             | Tree Canopy [m <sup>2</sup> green areas/m <sup>2</sup> area] |   | Canopy Cover [m <sup>3</sup> trees/m <sup>2</sup> area] |
|                                | Species Mix [N° Species]  |  |   | Species Distribution [N° Species]  | Tree Structure [N° Species]                                  |   | Urban Tree Diversity [N° Species]                       |
|                                | Age distribution [N° Age]   |  |   | Age Distribution   | Shannon Index  |   |   |
|                                |   |  | Presence of Water Reservoirs [m <sup>2</sup> water areas/m <sup>2</sup> area] |  |  |   |   |
| ECOLOGICAL                     | Carbon Stored in Vegetation, Roots and Soil [% CO <sub>2</sub> removed]         | Extrapolation of Aerosol & Chemicals from the Atmosphere                       |   |  | Air Pollutant removal [% CO <sub>2</sub> removed]            |   |   |
|                                | Change in Atmospheric Fine Dust Concentration                                   |  |   | Decrease in Air Quality Pm10 removal [%Pm10 removed]                               | Clean Air Provision  | Air Quality Improvement                                     |   |
|                                | Change in Atmospheric CO <sub>2</sub> Concentration [% CO <sub>2</sub> removed] |  |   | CO <sub>2</sub> Sequestration [% CO <sub>2</sub> removed]<br>Temperature Reduction | Climate Regulation   | Greenhouse Gas Storage/Sequestration<br>Energy Conservation |   |
| Native Vegetation [N° Species] | Species Habitat Requirement, Distribution Capacity                              | Presence of Species or Abiotic Components                                      | Native Vegetation   | Ratio of Native Trees  | Biodiversity   | Habitat Provision   |   |
|                                | Soil Porosity, Moisture Content   | Erosion Protection   |   | Soil Infiltration  | Water Regulation, Clean water Provision                      | Storm Water Control   |   |
|                                | Soil Organic Matter Content   | Erosion Protection   |   | Soil Infiltration  | Soil Erosion Protection                                      | Available Growing Space                                     |   |
|                                | Soil Water Holding Capacity   |  |   | Soil Bulk Density  |  |   |   |
|                                |   |  |   | Soil Nutrients   |  |   |   |
|                                |   |  |   | Soil Fertility   |  |   |   |

**Table 2.** *Cont.*

| Target       | Indicators Set Unit of Measurement  |  |                                   |   |                           |  |
|--------------|---|--|-----------------------------------|---|---------------------------|--|
| STRUCTURAL   | Houses Sold at Green Locations  | Protection against Flood Damage        | Condition of Publicly Owned Trees | Crown Dieback Damage to Infrastructure            | Tree Risk                 |  |
|              | Residential Area at Green Locations   | Landscape Features Attractive Wildlife |                                   | Income>Returns from Land-based Production         | Property Value Benefits   |  |
| RECREATIONAL | Noise Level, Accessibility for Recreants, Length of Walking Tracks, Degree of Naturalness, Number and Location of Research Facilities, Visitor Centres and Information Boards |  | Species Suitability               | Leaf Area and Distance to Roads; Recreation Cover | Recreation and Ecotourism | Human Health/Well-Being                            |
|              |   |  |                                   | Type of Foliage Tree Biomass                      | Aesthetic                 | Visual Access to Nature, Physical Access to Nature |

## 2.2. Performance Indicators for Net-Zero Energy Buildings Projects

In light of the reflections made in the premise of Section 2, in order to express and be able to quantify the levels of energy performance of the building in view of the technological solutions chosen to build the construction, it is possible to use a series of indicators through which to monitor the life cycle of the building from the energy point of view.

Various performance indicators are available for benchmarking different building attributes or characteristics, facilitating decision making, assessing specific project requirements or ensuring compliance with regulations and norms. These indicators quantify what one is trying to achieve and thus may need to select and use one or several of them at different stages of their work or process.

From the examination of some case studies in literature by means of search query on search engines (SCOPUS and Google Scholar) and normative documents on energy efficiency methods to be applied in the building and infrastructure sector [46–49].

The main indicators used for energy performance building (Table 1b) are grouped into three Key Sectors (Table 1a) according to the type of indicator considered and the evaluation objective set. The evaluation variables (Table 1c) used to quantitatively and/or qualitatively measure the *i*-th indicator are specified for each Sector. Finally, some project orientations are outlined according to the type of indicator and the Key Sector of reference (Table 1d).

Specifically, the following indicators.

- Within the Energy Sector (Net Energy Demand, Primary Energy Consumption, Primary, Energy Ratio, CO<sub>2</sub> emission) allow to measure the energy requirements of the building, as well as the level of energy consumed during its life cycle.
- Of environmental quality (Daylight Factor, Visual Comfort, Predictive Mean Vote and Percentage People dissatisfied) allow the Health Perception to be assessed on the basis of the level of well-being perceived by residents within the living spaces of the building.
- Of the economic and financial type (Cost Optimal Level and financial convenience of investing in energy efficiency measures) performance of the building make it possible to assess the economic benefit, in terms of lower construction, maintenance and management costs during the operation phase of the building, as a result of the construction of buildings constructed with energy-efficient technological components, such as the convenience to invest in Net-zero Energy Buildings Projects.

## 2.3. Performance Indicators for Urban Forestry Projects

In the case of Urban Forestry Projects, it is necessary to take into account criteria and indicators related to three types of Targets: the psycho-physical well-being of citizens (Recreational Targets), the protection of natural–environmental components and the enhancement of existing agricultural characterising the intervention area (Environmental Targets), the economic–productive and sociocultural development of the territory part of interest (Structural Targets) [50]. The achievement degree of each target can be expressed through appropriate evaluation criteria and corresponding performance indicators useful to detect in quantitative and qualitative terms the effects that urban forestry interventions generate on the territory and the built in ecosystemic key. At the beginning of the second half of the last century, the indicators most used with reference to Urban Forestry Projects made it possible to resolve mainly ecological–environmental evaluation issues [41,51] and rarely of a financial, social or cultural nature [52,53]. The latter are beginning to take on greater importance in the first decades of the 21st century, in relation to the growing attention paid to sustainable urban development issues. From the study of known cases in the literature, Table 2 shows, in chronological order, the main indicators used to assess the impacts produced by urban forestry interventions. For each of them, the corresponding unit of measurement and the reference target are specified. In particular, the main ecological indicators are Canopy Cover, Species Distribution, Air Pollutant Removal and Soil Fertility; the structural ones are Property Value Benefits, Land-Based Production. At the end, the principal Recreational Target indicators are Visual and Physical Access to Nature, Human Health/Well-Being.

Depending on the natural and socioeconomic characteristics of the intervention area, it is possible to establish the type of indicators to be considered in the evaluation phase, always respecting the type of Target considered and the evaluation question posed. The indicators most frequently used to assess urban forestation actions concern parameters related to the urban context of reference (e.g., not exhaustive, the level of accessibility of the area and the corresponding degree of infrastructure), others of a financial nature (e.g., nonexhaustive and the increase in the market value of the properties facing the forested area), environmental (e.g., nonexhaustive and the index on biodiversity) and sociocultural (e.g., nonexhaustive, the presence of areas intended for recreational activities).

In particular, with an ecosystem approach that allows measuring the benefits of urban green integrated with environmental quality strategies, it is possible to identify the optimal compromise solution with respect to the types and composition of vegetation that maximises the overall environmental quality. In urban spaces, the choice of species to be used must meet a set of criteria dictated by the environmental context of the site in relation to aspects related to: compliance with the characteristics of the landscape and nature, the depth of the root system, tolerance to biotic and abiotic stress, rapid growth, low emission of Volatile Organic Compounds (VOC), high capacity for environmental mitigation, etc.

The objectives set should be the basis for the choice, i.e., in relation to the

- CO<sub>2</sub> sequestration through essences with a high or medium capacity of CO<sub>2</sub> sequestration that allow to obtain the best results of compensation of the CO<sub>2</sub> deriving from the anthropic activities;
- potential absorption of gaseous pollutants with trees characterised by medium/high potential gas absorption values to reduce the high concentration of gaseous pollutants;
- potential dust capture by tree species with medium/high potential dust capture values, as much as in environmental contexts defined by a high level of fine dust pollution; and
- emission of VOCs and ozone formation potential by species with low or no emission of volatile organic substances in areas such as urban or industrial areas with pollution that are characterised by high concentrations of nitrogen oxides.

#### *2.4. Performance Indicators for Integrated Ecosystem Projects*

Where it is intended to integrate energy efficiency measures with those of forestation, some indicators used for Urban Forestry Projects can be referred to the assessment of the performance level about technological components chosen to create specific building part.

From the comparison between the indicators used to estimate the energy performance of the building and those corresponding to the benefits by forestation, some logical–functional relationships are identified. These correspondences link the Performance Indicators of each Key Sector and the corresponding Evaluation Variables of the Energy Sustainable Projects to those of the Urban Forestry Projects according to the type of reference Target of reference. For example, not exhaustive, the Net Energy Requirement of the building may depend on the Land Use component, in particular on the Form Coefficient of the building, which measures how much of the free area to be transformed is still impermeable (soil consumption). Furthermore, the value of the Daylight Factor, which expresses the level of environmental quality of the spaces inside the building and can be expressed in terms of the number of sunshine hours perceived during the months of the reference year, may vary depending on the natural component (Natural Component) inserted in the area facing the building and the type of tree species planted (Index of Plant Biodiversity). Thus, some indicators (Common Indicators) are identified with which to measure the effects produced by settlement transformation interventions carried out by means of integrated ecosystemic logics. Figure 1 shows the system of relationships between indicators used to evaluate Urban Forestry Projects and Energy Sustainable Projects.

In the following some indicators are illustrated through which to measure the multiple benefits deriving from IEPs.

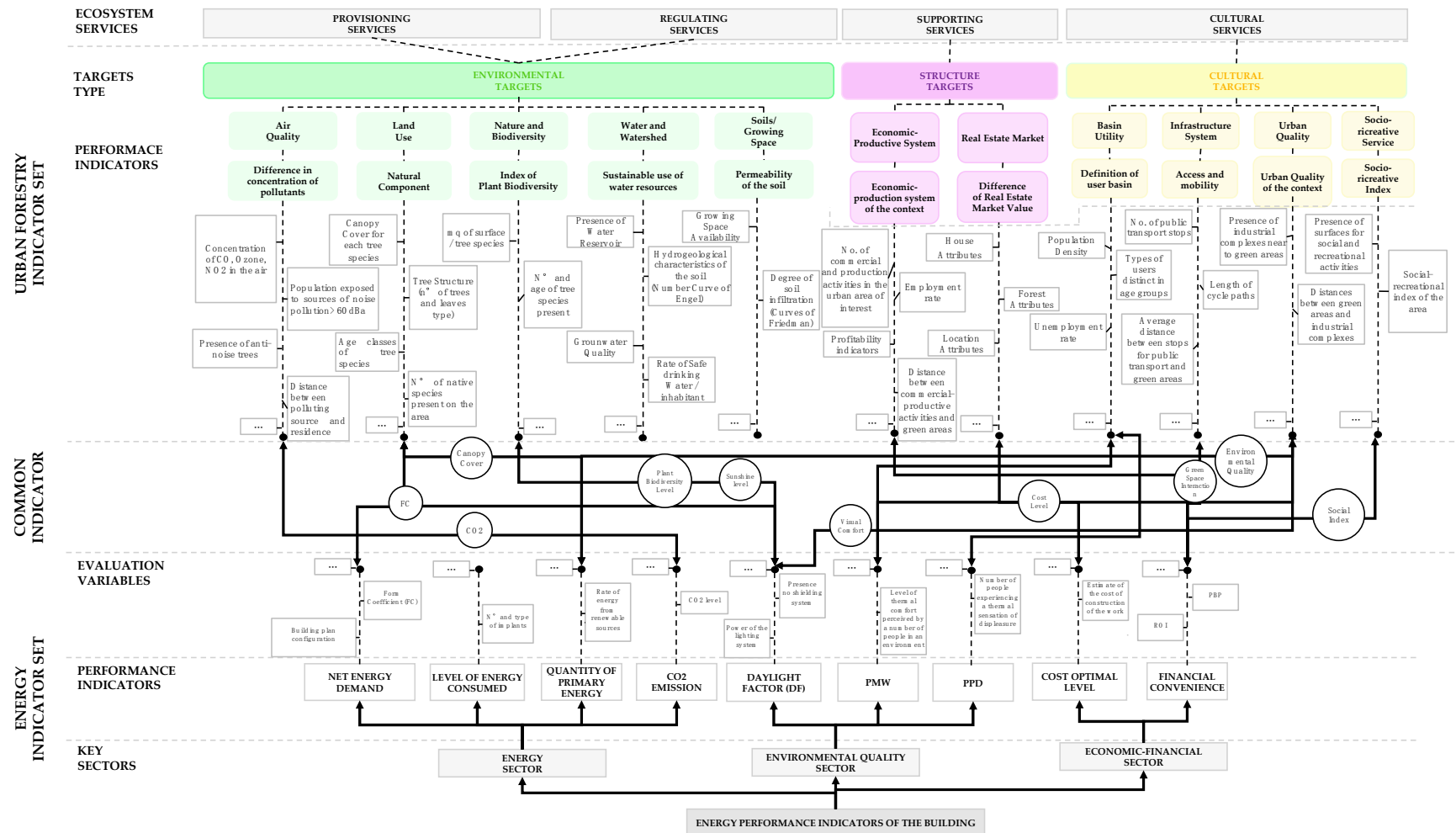


Figure 1. Indicator sets for integrated ecosystem projects.

The evaluation of settlement transformation projects based on the integration of energy efficiency measures and urban forestation in an ecosystemic key passes through the identification and estimation of both costs and economic–financial benefits related to Integrated Ecosystem Projects.

In view of the possible costs characterising the IEP, it is necessary to identify and express quantitatively and/or qualitatively also the benefits generated in an ecosystemic key by means of the integration between energy and nature.

These are multiple effects (environmental, social, economic–financial) deriving from the consequences produced by forestation on the construction according to an integrated relationship of reciprocal ecosystemic interaction. Each type of effect can be measured by using an appropriate performance indicator. The choice of appropriate indicators with regard IEP depend on specific evaluation problem to be solved and corresponding reference target. Specifically, in function of evaluation problem type the utilisable indicators can be that of Table 1 and/or urban forestry's ones according to an integrative logic, or not.

Each indicator can be estimated using quantitative and/or qualitative measurement methods. In the case of qualitative methods, which are used when it comes to indicators referring to social and environmental-perceptive aspects that are difficult to compute numerically in an objective manner, a scale of values is used according to which to assign a score in increasing measure, or not, depending on the degree of satisfaction of the evaluation objective set.

With regard to the cost items that must be taken into account during the evaluation phase on IEP, some of them refer to the intervention of energy efficiency, as in the case of the construction of the external coat of a new building and/or existing, others strictly relate to the costs to be incurred with reference to the forestation project planned on the intervention area. In particular, a part of the costs underlying Energy Sustainable projects involves the design, construction and implementation of technological solutions used to realise the building; another, however, concerns its life cycle, its management and possible routine and extraordinary maintenance. Their estimation can be carried out analytically by drawing up an appropriate metric estimate, or by performing a synthetic–comparative procedure based on the identification of parametric costs of the building in question. Below (in Section 3 on the case study), the costs of the realisation of the external coat of a building for civil housing on a parametric basis are estimated.

The valuation phase concerning both costs and economic–financial benefits is included in the proposed evaluation approach illustrated in the following subsection. It is built by integrating the phases of urban forestry interventions with those of energy efficiency projects for the building. Among the steps thus defined, 3 and 5 include the implementation of analytical approaches and the execution of numerical calculations aimed at quantifying the economic benefits produced by IEP.

The mathematical procedures used to express the types of ecosystemic effects that the presence of natural elements can generate both on the building and on the environment facing the building (for further information see Section 3.4 onwards of the case study analysed) are based on data and information extractable from known cases in the literature regarding the measurement of ecosystemic services generated by the relationship between the “natural system–building–urban/territorial structure of the intervention area.”

### *2.5. A Multicriteria Evaluation Approach for Settlement Transformation Interventions Carried out in an Ecosystemic Key Useful for the Identification and Sizing of Eco-Compatible Technological Solutions*

The methodological approach that is proposed to evaluate settlement transformation interventions according to ecosystemic logic is developed using principles of multicriteria analysis. On the basis of these principles it is possible to identify the relationships between the elements characterising the evaluation problem considered through functional links between multiple parameters of different nature in order to restore a unified understanding of the case type to be solved.

Specifically, the execution of processes aimed at a change of the territory that jointly take into account aspects related to urban forestry and the construction of energy-efficient buildings passes

through the definition and identification of a series of phases with an iterative and interactive process of definition and evaluation of alternative solutions to be adopted. These phases are related to the type of project actions that are taken into account in the definition of intervention solutions of the “forest” and “energy efficiency” considering the mutual interrelationships among them.

The steps characterising specifically the realisation of interventions aimed at the forestation of defined portions of urbanised territory, are made of

- analysis of the environmental and natural, morphological and infrastructural ecosystem of the territorial context in which the project is located. It is crucial to highlight the critical points and opportunities of an ecological/natural nature to be taken into account during the design process. The criticalities and opportunities identified make it possible to prefigure the objectives and design strategies to be pursued also in relation to the results of the subsequent phase of identification and selection of the most suitable arboreal species to respond adequately to the general and specific objectives set and specified according to the ecological needs characterising the area to be redeveloped;
- identification and selection of possible native arboreal/arbustive species, developed according to the environmental, morphological and infrastructural characteristics of the area highlighted during the previous phase, taking into account the performance characteristics of the species considered. These characteristics are expressed by means of appropriate performance indicators (CO<sub>2</sub> rate; reduction of the sound pressure level in the air) able to express and measure quantitatively/qualitatively the effects, expressed in terms of ecosystemic services, due to the presence and/or systematic inclusion of natural elements on the area subject to intervention;
- identification of the disposition of the arboreal/arbustive species chosen in relation to the evaluation of the ecological/environmental, economic and social effects on the urban context of reference and with respect to the level of performance within the intervention; and
- design of planting and maintenance methods for shrub and tree species and services for users to be included in the area.

Also, with regard to the construction/recovery of a building or an urban renewal project, it is necessary to take into account a series of aspects that have mutual interference, and consequently on the objectives and strategies to be pursued in the design process. In particular, the following aspects refer to (i) the site (bioclimatic, environmental, urbanistic, positional and sociocultural conditions), (ii) the building (possible layout in the lot, orientation, its relations with nearby buildings and infrastructures and market surveys on supply and demand in the energy, construction, purchase/rental of buildings and services sectors).

Thus, with regard to the steps to be taken to achieve sustainable energy-efficient buildings, the following are carried out.

- Analysis of the reference context of the site in which to carry out the intervention, which is both bioclimatic and aimed at discovering the exploitable energy potential of the geographical location where the construction is made (night/day air temperature, altitude, relative humidity, rainfall, etc.); orientation of the area, solar radiation and characteristics of ventilation; natural resources present/available: solar energy and geothermal lift, both related to the urban environment; existing and/or planned neighbouring buildings, their shape, style and distance; elements characterising the territory and the surrounding landscape in the changes introduced by the productive use of agriculture, industry, tourism, etc. and presence/access to groundwater/surface water collection; situation of traffic, noise and the sources that produce it; air quality in relation to pollutants; and type and distance of infrastructure—transport, energy supply (e.g., district heating systems and renewable sources), social and cultural services offered, demographic and economic characteristics.
- Definition of intervention strategies aimed at identifying the most efficient (i) form and layout of the building(s) in the lot, as well as its typological, distributive and defining articulation: the possible functional internal and external space; the modalities/strategies of thermal zoning

- (including internal/external transition zones and the passage of sunlight), ventilation, passive air conditioning, air distribution, flexibility of use and possible future adaptations); (ii) of the facades (ratios between opaque and transparent surfaces, solar shading solutions, daylighting systems, ventilation openings, etc.); and (iii) building design and layout, as well as its typological and distributive articulation, defining (i) the shape and layout of the building(s) in the lot, as well as its layout, defining its distribution, defining the methods/strategies of thermal zoning (including internal/external transition zones and the passage of sunlight), of ventilation, of passive air conditioning, of air distribution, of flexibility of use and of possible future adaptations); (iv) of the facades (ratios between opaque and transparent surfaces, of daylighting, of ventilation openings, etc.); (v) of the building's design. (iii) Building envelope also in relations with plant and construction systems (structural system, cooling/cooling, insulation, incorporated/consumed energy, resource use and impact of production, durability and maintainability, thermal mass, hygroscopicity, indoor air quality/volatile organic compound emissions, waste management and recycling potential).
- Identification of reference parameters for measuring the energy performance of the building relating to: the energy requirements of the building as a function of the most common climatic and management conditions relating to the shape/layout of the building in the lot, internal arrangement of functions and environments (parameters relating to lighting, ventilation, crowding, etc. and the energy consumption of the building, i.e., the energy performance of the building understood as the amount of energy, calculated or measured, needed to meet the energy needs related to normal use of the building, including, in particular, the energy used for heating, cooling, ventilation, hot water production and lighting to the potentials.
  - General identification of the location, shape and external and internal articulation of the building.
  - Design and evaluation of the alternative solutions of the technological/plant/structural components of the construction and choice of the optimal solutions to create an energy efficient building in compliance with the minimum regulatory parameters to be respected.
  - Measurement of the energy performance of the building and identification of the financial and economic costs and benefits of the intervention.

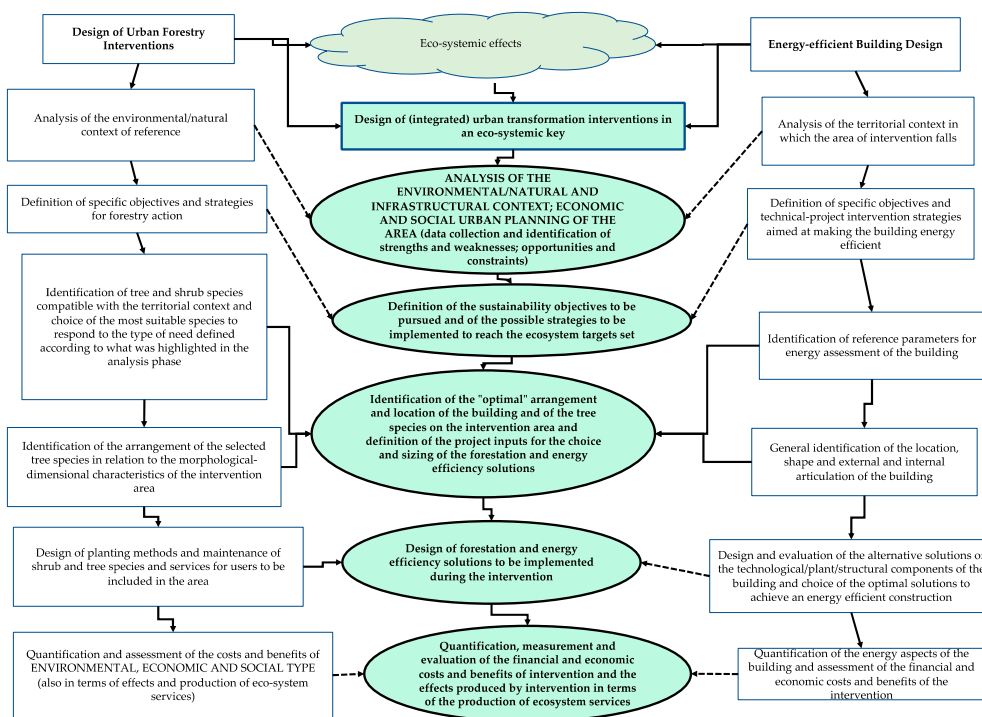
By integrating the phases characterising the two modes of intervention illustrated above (Figure 2), the structuring of the proposed methodological approach can be synthetically articulated in an integrated interactive and iterative process structured in the following phases.

- (1) Analysis of the environmental/natural context, of the bioclimatic and infrastructural conditions; urban, economic–social conditions of the area undergoing settlement transformation in order to collect the data necessary to describe the actual state of the area and identify its strengths and weaknesses, opportunities and constraints.
- (2) Definition of the specific sustainability objectives to be pursued and of the possible strategies to be implemented to reach the ecosystemic targets related to the bioclimatic, environmental, naturalistic, settlement, infrastructural, socio/economic conditions of the reference context.
- (3) Identification of the “optimal” arrangement and location of the building and of the tree species on the intervention area, in the reciprocal interactions in relation to the environmental effects and the ecosystemic targets to be pursued, and definition of the project inputs for the choice and sizing of the tree species and of the technological/plant/structural solutions of the building.
- (4) Design of forestation and energy efficiency solutions to be implemented during the intervention.
- (5) Quantification, measurement, evaluation of the financial and economic costs and benefits of the intervention and the effects produced in terms of the production of ecosystem services (based on the results of the calculation of the energy audit of the building and the ecological/environmental outcomes produced by the forestation).

Overall, this articulation makes it possible to verify the effects of settlement transformation interventions developed in an integrated ecosystemic key within consolidated urban contexts.



Within the proposed methodology, the quantification of some environmental benefits deriving from forestation (as in the case of the reduction of the noise pollution rate due to the soundproofing power of trees and the reciprocal positioning between the building and the polluting source) is carried out on the basis of evidence of physical-experimental derivation; others, however, (for example, not exhaustive, Visual Comfort) are calculated through qualitative assessment methods. The output of the calculation procedure for the measurement of environmental effects derived from urban forest interventions is then considered as a reference parameter for the choice of design solutions for energy building efficiency.



**Figure 2.** Evaluation methodology for settlement transformation interventions developed in an integrated key with urban forestation projects.

In general, a series of indicators must be taken into consideration to express the multiple ecosystem effects generated by taking into account, from the initial steps of intervention defining and the possible interrelationships and implications between choices relating, to the inclusion of forestation elements and building design choices about the definition of technological and plant solutions to be adopted in the construction so that it has zero emissions. In the case study of Section 3, the proposed methodology has been developed with reference to phases 5 and 6 considering, as an example, the definition of the technological solution relating to the characterisation of the external facade of the building adjacent to the area directly affected by the specific urban forestation intervention, identified in its relationship with the location of the building through the development of the previous phases (phases 1–3). This is also in order to make it as clear as possible in a synthetic way how to proceed in phase 5 to define the technological and plant solutions, and in phase 6 to quantify the ecosystem benefits. For each of the indicators considered, in relation to the objectives defined in phase 2, the method of measurement and the corresponding unit of measurement are specified (see Table 3). The procedure aimed at the analytical computation of the value of each is therefore within the proposed evaluative methodology considered to highlight how and why they should be favoured design practices of design choices in an integrated ecosystemic key. The complete development of technological and plant solutions to be adopted in the building in relation to the choices adopted in the initial stages of the proposed methodological procedure will allow a more complete quantification of the ecosystem benefits induced by the adoption of the proposed procedure.

**Table 3.** Set of indicators for Integrated Ecosystem Projects (IEP).

| Targets       | Proposed Indicators      | Type of Measurement System |             | Measurement Method  | Unit of Measurement          |
|---------------|--------------------------|----------------------------|-------------|---|------------------------------|
|               |                          | Quantity                   | Qualitative |   |                              |
| Environmental | CO <sub>2</sub> rate     | •                          | •           | Calculation of carbon dioxide abatement on the basis of the tree species concerned  | Kg of CO <sub>2</sub> seized |
|               | Air sound pressure level | •                          | •           | Determination of the rate of decrease of the sound pressure level as a function of the arrangement of the considered arboreal species and of the distance from the polluting source   | decibel (dB)                 |
|               | Plant Biodiversity Level | •                          | •           | Number of tree and bush species included as a result of the project   | N°                           |
| Social        | Green-Space Interaction  |                            | •           | Distance between the intervention area and the green areas in the context   | Linear meter                 |
|               | Visual Comfort           |                            | •           | On the basis of the amplitude of the angle of the visual cone in the direction of areas considered to be beautiful landscapes; Visual Comfort is estimated by assigning an increasing number of points according to the scale of values [0,3,6,9] | N°                           |
| Structure     | Cost                     | •                          |             | Estimate of the cost items for the construction of the building and/or parts thereof, as well as those relating to the arrangement of the greenery according to the tree species considered   | €                            |

### 3. Case Study

The applicability of the methodological approach proposed has been verified by hypothesising the design of a settlement transformation intervention for the redevelopment of a lot located on the outskirts of the Rome city on which to construct a new building for social housing.

On the basis of the environmental, morphological and urban characteristics of the area, the objective is to carry out a settlement transformation including forestation. This takes into account the multiple benefits on an urban and building scale that the presence and/or insertion of arboreal/arbustive elements can produce also with regard to the choice, design and sizing of the technological solutions of the building organism to be realised and/or preserved. In particular, on a building scale, we focused on the interactions between the insertion/arrangement of species of trees/bushes and technological solutions of the outer shell (facade) of the elevation directly overlooking the part of the lot on which it is planned to insert trees. In the following, some possible indicators are illustrated, able to jointly measure the benefits deriving from IEPs in an integrated ecosystemic key. Subsequently, the analyses and results of the elaborations carried out in the phases of the methodological approach previously illustrated in Section 2 are briefly described.

#### 3.1. Context Analysis

The area of study (2080 square metres) faces the high-speed road (Anagnina Road), not far from the Grande Raccordo Anulare (Ring Road) of the city of Rome and Ciampino airport, near the natural agricultural area of Gregna. The lot is partially occupied by three buildings (3640 cubic meters). The design hypothesis adopted is to remove these buildings and to build a new one in compliance with the existing volume.

The high level of traffic on Anagnina Road during most of the weekdays is a source of pollution, both in terms of noise and air quality, for the psycho-physical health of citizens. From an on-site survey carried out using instruments for measuring partial air pressure, it was possible to estimate the acoustic intensity coming from Anagnina Road at 80 dB, which corresponds to a noise level capable of causing personal injury [54]. In addition to surveys aimed at estimating the sound pressure level characterising the intervention area, data concerning the temperature, sunshine, ventilation, vegetation structure of the intervention area as well as information on the real estate market in the urban area of reference were also collected and processed.

From an ecological–environmental point of view, the existing arboreal/arbustive species are often not of an autochthonous type and do not appear to be located according to a precise distribution logic with respect to buildings and roadways, so as to make the area on which to act totally exposed to solar radiation.

#### 3.2. Definition of Specific Sustainability Objectives and Possible Intervention Strategies

From the analyses carried out, it emerges that in the project development solutions must be pursued that aim to

- minimise land consumption according to the layout of the building on the lot;
- allocate the greater part of the available land area to the planting and arrangement of the arboreal/arbustive species identified in respect of the ecological/natural vocation of the area in which the lot falls (for further information on the method of tree selection, see Section 3.4.2);
- improve the acoustic–environmental conditions of the intervention area;
- identify the optimal orientation of the building according to the level of sunshine that characterises the area during the entire reference year;
- ensure a good view of the Roman Agro facing the Anagnina Road; and
- encourage the interconnection between the green areas present in the area in which the intervention area falls.

The structural system chosen for the construction of the entire building is that with XLAM type panels, which have characteristics of sustainability expressed in terms of impact on the environment and energy savings, seismic resistance and fire resistance. In fact, the use of XLAM wood panels produces effects from an environmental point of view because it uses small amounts of energy for its production, performance and energy both direct (the energy used in the production process is much lower than that required for the construction of homes with reinforced concrete or brick) and indirect (energy consumption will be much lower than a “classic” building made of masonry); the construction times and costs, which are lower than those of a traditional masonry building, as are the construction times (and consequently any demolition); and seismic resistance, since wood is a material with very low stiffness, and its lightness allows it to respond better to the stresses of an earthquake and to absorb the energy of a possible earthquake. The choice of this type of construction is carried out in compliance with the natural characteristics and climatic conditions of the context of intervention, as well as in consideration of the regulatory provisions on thermal-acoustic comfort to be ensured in the living environments of the building [55].

### 3.3. Set of IEP Indicators

The proposed set of indicators is constructed taking into account the objectives to be pursued illustrated in Section 3.2. For each of the indicators considered, the method of measurement and the corresponding unit of measurement are specified.

Table 3 shows the indicators chosen for assessing integrated ecosystem projects. Some allow estimation of the environmental and social benefits produced by IEP; others allow estimating the possible costs to be considered during the evaluation and formulation of economic–financial convenience judgments about the intervention type considered. With regard to the financial aspect of the projects developed in an integrated ecosystemic key, only the cost of creating the outer coat of the facade of the building in the direction of Via Anagnina was estimated, as well as the planting and management costs of the tree species considered.

### 3.4. Determination of the Input Parameters Considered for the Design of Eco-Compatible Technological Solutions

#### 3.4.1. Identification of the Layout and “Optimal” Location of the Building in the Lot

The process of defining the best design configuration with respect to which to position the building in the “optimal” way possible is conducted in accordance with the objectives outlined above.

An appropriate benchmark can be matched to identify the optimal design configuration. The parameters associated with each objective are summarised in Table 4. In particular, the mathematical formula about Sunshine Level depends by the number of sunshine hours (per day) obtained in function of the orientation of the building plan and the latitude of the reference geographical place. In the case study, the building plan is rotated of about 20° in clockwise direction, and the latitude of reference is that of Rome city (42° North).

The Figure 3 shows how the optimal design configuration was defined with reference to the calculation of the values of the parameters in Table 3.

Table 4. Parameters for the optimal design configuration.

| Objectives                                | Parameters for Defining the Optimal Design Configuration | Procedure Computing   | Unit of Measurement           |
|---|--|---|-------------------------------|
| Lower consumption of soil                 | Nonpermeable surface                                     | $\frac{\text{Cemented surface}}{\text{Lot surface}} \times 100$   | %                             |
| Maximum green area                        | Permeable surface  | $\frac{\text{Surface destined for green}}{\text{Lot Surface}} \times 100$   | %                             |
| Optimal acoustic–environmental conditions | Distance between building and noise source               | Linear measurement between the external facade of the building and the edge of the lot tangent to the road  | Linear meter                  |
| Better orientation of the building        | Level of Sunshine  | <p>Calculation of the number of annual sunshine (<math>S_{tot}</math>) according to the expression:</p> $S_{TOT} = \sum_{i=1}^{12} n_i \times g_i$ <p>in which:</p> <p><math>n_i</math> = No. of hours of sunshine per day calculated on the basis of the orientation of the plan building) and latitude of geographical reference place</p> <p><math>g_i</math> = No. of days of the <math>i</math>-th month</p> | Dimensionless numerical value |
| Uninterrupted view on the area of Gregna  | Qualitative Scale [0,3,6,9]                              | <p>Amplitude of the angle of the visual cone (<math>\alpha</math>) in the direction of the <i>Agro Romano</i>:</p> <p><math>0:0^\circ &lt; \alpha &lt; 25^\circ</math></p> <p><math>3:25^\circ &lt; \alpha &lt; 50^\circ</math></p> <p><math>6:50^\circ &lt; \alpha &lt; 75^\circ</math></p> <p><math>9:75^\circ &lt; \alpha &lt; 100^\circ</math></p>  | Dimensionless numerical value |



**Figure 3.** Optimal design configuration. (Source: Elaboration from E. Sonnino's tables degree thesis at the Architecture Faculty of the Sapienza University of Rome -IT).

### 3.4.2. Identification of the Arboreal/Arbustive Elements to be Inserted in the Urban Context of Reference (Forestation)

The phase of identification of the arboreal/arbustive elements to be included in the urban context of reference was carried out taking as reference the study of ISPRA (2015) [56] on the census of the main tree species in Rome.

In order to carry out an ecosystemic intervention in respect of the ecological–environmental characteristics of the territory, each of the species selected by ISPRA is evaluated according to

- morphological criteria (botanical and ecological characteristics, environmental mitigation capacity);
- performance capabilities (mitigation of noise and air pollution, decrease in the rate of CO<sub>2</sub> in the air and increase in local biodiversity);
- dimensional parameters of the individual species to be planted on the intervention area according to the layout of the building and in consideration of the buffer strips that must be ensured during the design phase of the part of surfaces to be allocated to greenery; and
- unit cost of planting.

Figure 4 shows the tree and shrub species described in the ISPRA document (2015) classified and described on the basis of the above criteria.

In particular, the species considered most suitable to pursue the objectives aimed at reducing sound pressure according to the distance of the building from the polluting source and the type of tree, as well as the concentration of CO<sub>2</sub> due to the planting and arrangement of the selected species, were selected. This also takes into account the dimensional characteristics of the tree and/or shrub depending on the surface area of the lot to be forested and the potential capacity for environmental mitigation in relation to the potential for total sequestration of CO<sub>2</sub> per plant in 20 years of planting (tonnes), emission of VOC in µg/g foliar dry weight/hour, ozone potential formation (g of O<sub>3</sub>/plant/day), absorption of gaseous pollutants and dust capture [57].

Table 5 shows the selected species to be included in the part in front of the building to be built with the relative parameters of potential environmental mitigation capacity. In last column of Table 6 the Environmental Mitigation Capacity (EMC) parameter corresponds to the plant attitude of sequestering CO<sub>2</sub> in atmosphere. To measure it, it has been expressed with a qualitative judgment (Bad, Good, Better) according to level of CO<sub>2</sub> sequestration per plant in tonnes (t). If  $t < 0.1$  the EMC is bad; if  $0.1 \leq t \leq 1.5$  it is Good; if  $t > 1.5$  the EMC is Better.

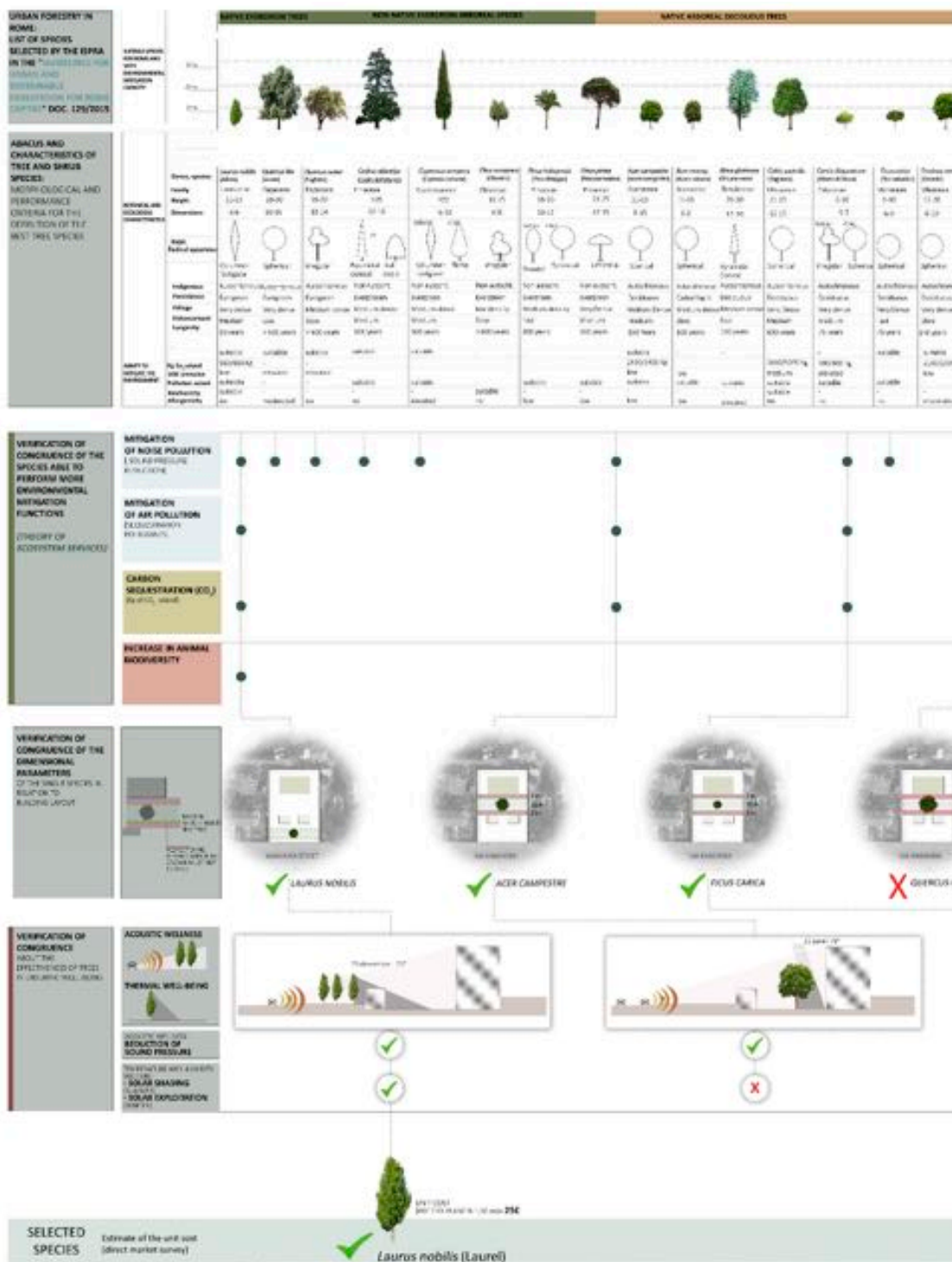
**Table 5.** Selected arboreal/arbustive species: potential environmental mitigation capacity.

| Selected Species               | Total Sequestration of CO <sub>2</sub> per Plant in 20 Years of Planting (Tonnes) | Emission of VOCs (µg/g Leaf Dry Weight/Hour) | Ozone Potential Formation (g of O <sub>3</sub> /Plant/Day) | Absorption of Gaseous Pollutants | Dust Capture | Environmental Mitigation Capacity |
|--------------------------------|---|--|--|----------------------------------|--------------|-----------------------------------|
| Laurus nobilis (Laurel)        | 0.4<br>(Low)  | <1<br>(Low)                                  | <1<br>(Low)  | Medium                           | Medium       | Good                              |
| Acer platanoides (Curly maple) | 3.8<br>(High)   | <1<br>(Low)                                  | <1<br>(Low)  | High                             | Medium       | Better                            |
| Viburnus tinus (Viburnum vat)  | 0.4<br>(Low)  | <1<br>(Low)                                  | <1<br>(Low)  | Medium                           | Medium       | Good                              |

Source: Institute of Biometeorology (IBIMET) of the CNR of Bologna; Urban forestry: criteria for the selection of tree and shrub species for environmental mitigation, 2017 [57].

**Table 6.** Selected arboreal/arbustive species: number of units to be planted and corresponding unit prices.

| Selected Species               | Type of Vegetation | Number and/or Linear Metre of Plants | Unit Price          |
|--------------------------------|--------------------|--------------------------------------|---------------------|
| Laurus nobilis (Laurel)        | Shrub              | 21 plants                            | 25.00 €/plant       |
| Acer platanoides (Curly maple) | Tree               | 3 plants                             | 180.00 €/plant      |
| Viburnus tinus (Viburnum Vat)  | Shrub              | 31 linear metre (62 plants)          | 7.00 €/linear metre |



**Figure 4.** Example of classification, evaluation and identification of tree and/or shrub species to be included in the intervention area to be covered by greenery. (Source: Elaboration from E. Sonnino's Ttbles degree thesis at the Faculty of Architecture of the Sapienza University of Rome -IT)

Table 6 for each one specifies the number of trees and/or linear metres of shrub and the corresponding unit purchase price.

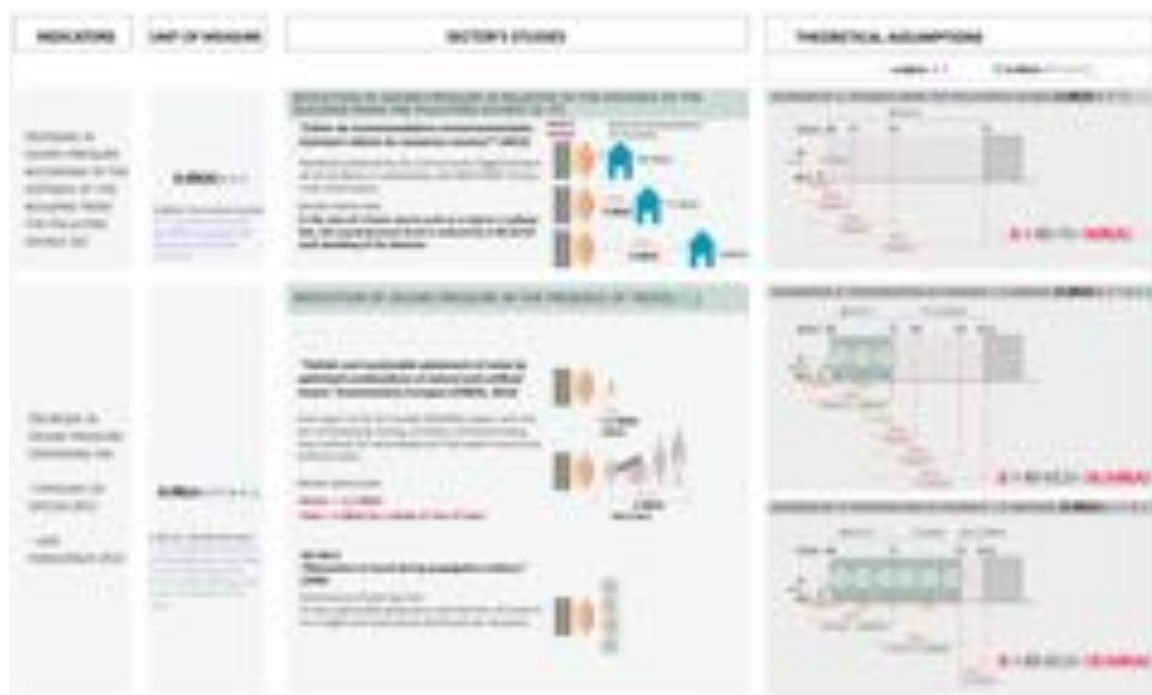


### 3.4.3. Measurement of the Decrease in Sound Pressure Due to the Distance from the Polluting Source and the Systematic Arrangement of the Selected Species

To measure the decrease in the level of noise pollution ( $\Delta dB$ ), it is necessary to take into account both the distance between the polluting source and the building to be constructed ( $\Delta dB_1$ ), as well as the dissipative capacity of the species considered in relation to their position on the free area of intervention and reciprocal positioning ( $\Delta dB_2$ ). With regard to the reduction of sound pressure due to the relative distance between the “pollutant-built source” ( $\Delta dB_1$ ), the study carried out by the French Noise Observatory in collaboration with the Communauté d’agglomération de Val de Bièvre (2012) states that “in the case of a linear source (road and/or railway line) there is a reduction in the sound pressure level of 3 dB at each doubling of the distance between the pollutant source and the built.”

Where there are tree and bush species between the polluting source and the building, in addition to taking into account  $\Delta dB_1$ , it is also possible to consider the beneficial contribution deriving from the location and positioning of natural elements ( $\Delta dB_2$ ). The Report of the European Commission on the HOSANNA project (2013), whose objective is to develop, verify and disseminate new methods for noise reduction using natural means, indicates that for 15 m of depth from the polluting source, the arrangement of a series of trees reduces the acoustic intensity by ~3 dB, while the possible insertion of hedges causes a decrease in sound pressure of ~1.5 dB.

On the basis of these data found at European-level, in the case of the area under study, the sound pressure abatement rate ( $\Delta dB$ ) is estimated numerically between the point where the noise level is measured and the building. This is based both on the physical distance between the pollutant source and the building, and on the inclusion of appropriate tree species useful for improving the acoustic quality of the air (Figure 5).



**Figure 5.** Theoretical scheme of the procedure adopted for the determination of the sound pressure reduction due to the insertion of tree elements and the building layout on the area of intervention. (Source: Elaboration from E. Sonnino’s tables degree thesis at the Faculty of Architecture of the Sapienza University of Rome -IT).

### 3.4.4. Determination of the Level of Felling of the Amount of CO<sub>2</sub> in the Atmosphere by the Effect of Trees

It is scientifically recognised that plant species need a certain amount of CO<sub>2</sub> for the development of chlorophyll photosynthesis. Therefore, arboreal/arbustive plants store high doses of carbon in order to reduce the concentration of pollutants in the atmosphere.

The CO<sub>2</sub> absorption capacity of the selected arboreal/arbustive species varies according to the

- reference environmental conditions and
- morphological and performance characteristics of the species considered (e.g., not exhaustive, the age and growth rate of the tree and the ability to mitigate air pollution).

Numerical data are provided in the literature [57] that express the ability of adult individuals of the tree species of interest to store CO<sub>2</sub> during their life cycle. In the case under study, the contribution of each of the selected species to the abatement of the rate of carbon dioxide in the atmosphere was estimated (Table 7), taking into account the values reported in Tables 4 and 5.

**Table 7.** Calculation of the total CO<sub>2</sub> abatement obtained through forestation

|  | Project Tree Species |                  |                |      |
|--|----------------------|------------------|----------------|------|
|  | Laurus Nobilis       | Acer Platanoides | Viburnus Tinus |      |
| CO <sub>2</sub> stored in twenty years [T/tree]      | 0.4                  | 3.8              | 0.4            |      |
| No. of trees planted                                 | 21                   | 3                | 62             |      |
| Total CO <sub>2</sub> stored in twenty years [Ttot.] | 8.4                  | 11.4             | 24.8           | 44.6 |

### 3.5. Design of Eco-Compatible Technological Solutions and Evaluation of the Benefits Deriving from Integrated Ecosystemic Interventions

Thus, on the basis of the parameters previously identified useful for expressing the degree of satisfaction of the environmental sustainability objectives set (mitigation of noise pollution and improvement of air quality) the identification, design and characterisation phase of the most suitable technological and construction solutions to respond jointly to the objectives set is conducted. Attention is paid to the sizing of the layers of material that form the outer coat of the facade of the building in the direction of Anagnina Road.

In order to highlight the benefits, both those that can be monetised (for example, the Cost Optimal Level defined on the basis of the cost items related to the technological components of the façade facing Via Anagnina) and those not necessarily measured in monetary terms (for example, the Visual Comfort and the Degree of Connection of the green space of the project with the existing green areas in the context of reference) that can derive from the development of settlement transformations conducted according to ecosystemic logic, two project scenarios are compared: (a) nonintegrated ecosystem design) and (b) integrated ecosystem design) conducted, respectively, (a) without considering the presence of natural elements and (b) taking these elements into account in the development of the intervention on the area.

For both project scenarios, the hypothesis that the arrangement of the materials making up the external coat of the study facade is the same is considered.

In the following, the two design scenarios (a) and (b) are compared, highlighting the differences relating to the external coat on the basis of the different thickness of the internal and external insulation layer, which is obtained following an integrated ecosystemic intervention (Section 3.4.1). Subsequently, (a) and (b) are compared, expressing both monetary (Cost) and non-monetary (Visual Comfort, Degree of interconnection between Green Spaces of the same urban context of reference and Level of Plant Biodiversity) benefits that can be obtained from settlement transformation interventions that include or do not include forest elements systematically arranged on the study lot (Section 3.4.2).

## Characterisation of the External Facade of the Building in the Direction of Anagnina Road. Definition of the Thickness of the Internal and External Insulation Layer

### *a. Integrated Non-Ecosystemic Design*

From the sound pressure level recorded on the S-W front of the building to be realised (70.0 dB) in the absence of trees and shrubs arranged in the part in front of the construction, the thickness of the internal and external insulation layer, made of rock wool and gypsum fibre, respectively, has been sized. In order to guarantee a noise level in the interior of the building of a maximum value of 25 dB or less, if the beneficial contribution of the trees has not been taken into account, the soundproofing power deriving from the design of the external wall corresponds to a value of 50 dB. This value is obtained considering the soundproofing properties of each layer making up the external cladding. Among these also the layers of thermal-acoustic insulation (internal and external) whose thickness, in the case of design not integrated with the natural system, is respectively of 6 and 10 cm.

### *b. Integrated Ecosystem Design*

If, on the other hand, an integrated design is carried out, i.e., the design and sizing of the elements making up the external cladding take into account the benefits of the trees relative to the reduction of acoustic intensity and the reduction of pollutants in the atmosphere, the sound pressure level recorded on the S-W front of the building corresponds to 61.25 dB. In this case, the soundproofing power deriving from the design of the external wall corresponds to a value of 40 dB, which is equivalent to the lowest acceptable value for the soundproofing capacity that the external lining of a building must have. Compared to case (a), the thermal-acoustic insulation layers are 4 and 8 cm thick, respectively.

### 3.5.1. Measurement of Monetary Benefits and Not in the Case of Settlement Transformation Interventions Conducted in an Integrated Ecosystemic Key

In order to evaluate the economic–financial convenience of the IEP, the construction costs for the external coat of the building's facade in the direction of Anagnina Road (Table 5) are estimated, as well as those relating to urban forestation in the part in front of the building (Table 6). Subsequently, some economic benefits are measured, expressed through the common indicators illustrated above.

The monetary benefits in terms of construction costs related to the outer coat of the S-W façade (Table 8) and the urban forestation system (Table 9) in front of the building were quantified as follows. Finally, some economic benefits have been evaluated (Visual Comfort, Green Spaces Interaction Factor, Plant Biodiversity Level and Environmental Quality) through a qualitative measurement system (Table 10).

From the calculation procedure aimed at the summary estimation of the realisation costs about the external coat of the building facade, both in the case of integrated ecosystem design (Cost.b = €264,000.00) and not (Cost.a = € 267,300.00) and those related to the design of the green area in front of the building (Cost forestry = € 2180.00), it is clear that the amount of expenditure to be incurred for the implementation of the urban forestry intervention planned on the intervention area is included in the differential cost between Cost.a and Cost.b (€ 3300.00). This produces a surplus of € 1120.00 of support to the promoter of IEP in the execution of further actions of requalification in favour of the recovery of the intervention area in consideration of the three types of ecosystemic Targets. Although the application was carried out with reference to a specific portion of the building, the cost analysis provides an indication of the financial convenience of implementing integrated design practices in an ecosystemic key for both public and private entities.

Moreover, the outcome of the qualitative evaluation of some noncash benefits deriving from IEP shows the economic feasibility of integrated ecosystemic interventions, especially in light of the many beneficial effects that these types of actions produce both with regard to the built and with regard to the economic, environmental and social development of the urban context of reference.

**Table 8.** Estimated construction costs of the outer coat of the building's S-W facade.

| Type of Design                       | Unit Cost of the Outer Coat of the S-W Façade (Including Labour, Excluding VAT) [€/sqm] | Total Façade Area S-W [sqm]                       | Total Cost of Construction of the Masonry Package [€] |
|--------------------------------------|---|---|---|
| a. Integrated non-ecosystemic design | 810   | 330   | Tot $c_{\text{ost.a}}$ = 267,300.00                   |
| b. Integrated ecosystemic Design     | 800   |   | Tot $c_{\text{ost.b}}$ = 264,000.00                   |
| $\Delta_{\text{Cost}} =$             |   | Tot $c_{\text{ost.a}}$ – Tot $c_{\text{ost.b}}$ = | 3300.00   |

**Table 9.** Estimation of costs related to urban forestation intervention.

| Cost Items Relating to the Implementation of the Green System on the Part of the Lot in Front of the Building |                  |                                    |   |                               |   |                           |
|---|------------------|------------------------------------|---|-------------------------------|---|---------------------------|
| Vegetation  | Species          | No. and/or linear metres of plants |   | Unit cost/shaft/business cost | Procedure computing                       | Cost total vegetation [€] |
|   |                  | Laurus Nobilis                     | 21 plants                                   |                               | 25.00 €/plant                             | $25.00 \times 21$         |
|   | Acer Platanoides | 3 plants                           |   | 180.00 €/plant                | $180.00 \times 3$                         | 540.00                    |
|   | Viburnum Tinus   | 31 linear metres                   |   | 7.00 €/linear meter           | $7.00 \times 31$                          | 217.00                    |
| Tot.  |                  |                                    |   |                               |   | 1280.00                   |
| Labour force  | Worker           | No. of workers                     | hours (h)/worker                            | Unit/worker cost per hour     | Procedure computing                       | Total labour costs [€]    |
|   |                  | 3                                  | 12 h<br>$H_{\text{tot}} = 3 \times 12 = 36$ | 25.00 €/h                     | $25.00 \times 36$                         | 900.00                    |
| Tot.  |                  |                                    |   |                               |   | 900.00                    |
| TOT.  |                  |                                    |   |                               | Cost forestry = Labour force + Vegetation | 2180.00                   |

**Table 10.** Estimation of the benefits not monetised in the case of both integrated and non-monetary ecosystem interventions.

| Type of Benefits Considered | Indicators                     | Quality scale [0,3,6,9] and Definition of Evaluation Range   | Type of Design   |    |    |
|-----------------------------|--------------------------------|--|--|----|----|
|                             |                                |  | a.   | b. |    |
| Benefits not monetised      | Visual Comfort                 | Opening angle of the visual cone ( $\alpha$ )  | 0: $0^\circ < \alpha < 25^\circ$<br>3: $25^\circ < \alpha < 50^\circ$<br>6: $50^\circ < \alpha < 75^\circ$<br>9: $75^\circ < \alpha < 100^\circ$                       | 3  | 6  |
|                             | Green Space Interaction Factor | Distance (d) between the intervention area and the green spaces present in the same reference area | 0: $600 \text{ m} < d < 1000 \text{ m}$<br>3: $200 \text{ m} < d < 600 \text{ m}$<br>6: $100 \text{ m} < d < 200 \text{ m}$<br>9: $50 \text{ min} < d < 100 \text{ m}$ | 6  | 6  |
|                             | Plant Biodiversity Level       | Number of plants inserted ( $n$ ) on the area subject to forestry                                  | 0: $0 < n < 30$<br>3: $30 < n < 60$<br>6: $60 < n < 90$<br>9: $90 < n < 120$   | 0  | 6  |
|                             | Environmental Quality          | Mitigation Capacity of CO <sub>2</sub> concentration in atmosphere (Tonnes, $t$ )                  | 0: Almost zero ( $0 < t < 10$ )<br>3: Low ( $10 < t < 30$ )<br>6: Medium ( $30 < t < 50$ )<br>9: High ( $t > 50$ )   | 0  | 6  |
|                             |                                |  | TOT.   | 9  | 24 |

#### 4. Conclusions

The need to consider the natural and the built environment together orients the planning of the territory towards alternative design strategies in view of urban sustainability. In this perspective, the systematic inclusion of new tree and/or shrub elements on portions of land to be regenerated; therefore, the realisation of Urban Forestry Projects allows pursuit of multiple objectives aimed at regulating the economy of the places, supporting the welfare of the population and provisioning to the protection of the environment and the rational use of land (ecosystemic services). This is particularly important where Urban Forestry Projects are to be carried out in conjunction with settlement transformation projects characterised by the construction of buildings according to the Net-zero Energy Buildings model. In this case the mixture of natural elements and building structures according to a relationship of mutual interdependence of an ecosystemic matrix is on the basis of Integrated Ecosystem Projects (IEP).

For the multidimensional character of IEP, it is necessary to resort to multicriteria analysis techniques useful to express effects of various kinds by means of appropriate performance indicators. The use of common indicators allows making judgements on IEP taking into account, through ecosystemic logics, both the forest component and the energy performance characteristics of the built environment.

With this work, starting from the study of the literature and the reference standard, it is first defined a set of indicators able to express the ecosystemic effects produced by IEP. The choice of performance indicators to be used in specific applications obviously depends on the evaluation problem to be solved, such as that concerning the energy characterisation of the building as a result of the design and construction of technological components sized on the basis of the effects produced by forestation, taking into account ecosystemic logic.

An evaluation approach for IEP is now proposed. The characterisation of the proposed approach uses the principles of multicriteria analysis. These principles are useful for taking into account, during the evaluation phase, indicators of a financial, but also environmental and sociocultural nature.

The role of the survey tool in urban planning and architectural design in an ecosystemic key is evident, as also shown by the case study developed, which demonstrates the effectiveness and ease of use of the evaluation approach for IEP illustrated in this study. In fact, from the proposed case study, in which attention was focused only on the realisation of the outer coat of a facade of the building in order to be able to express the benefit (of monetary, and not type) produced by the interaction between the natural environment and the built one, emerges the convenience, both in terms of costs and economic benefits generated by IEP, in performing an intervention in an integrated ecosystemic key. This portion of the certified study regards, specifically, the contribution of trees to noise reduction and CO<sub>2</sub> sequestration, and its implication for technological design.

The contextualisation of the parameters to different urban realities and the corresponding applicability checks of the evaluative approach supporting the execution of IEP with reference to the design of the technological components of the entire building, also considering other effects by tree presence (reduction of air temperature, wind shelter and diminution of heat losses and calculation of shadowing) outline interesting prospects for future research.

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