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# Carbon Sequestration and Habitat Provisioning through Building-Integrated Vegetation: A Global Survey of Experts

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**Abstract:** Carbon sequestration (CS) and habitat provisioning (HP) through building-integrated vegetation are interlinked approaches that could potentially reduce climate change and biodiversity loss attributed to the built environment. However, a practical approach is required to integrate CS and HP into building design. A two-stage approach was undertaken in this research; firstly, preparing a conceptual framework from an extensive literature review and, secondly, gauging the perspective of building industry experts on that framework through a survey. The survey was designed to determine expert opinion related to establishing the data gathering approaches, progressing to identifying strategies and methods to quantify them, and finally, monitoring performance indicators for achieving CS and HP goals. The results of descriptive analyses performed after data collection indicate a notable difference in opinions between built environment professionals (group A) and environmental scientists and researchers (group B). The findings indicate that respondents emphasized maintaining vegetation in order to maximize CS rates and biodiversity levels. Moreover, spatial ecology considerations, including landscape-level parameters (vegetative area coverage, habitat availability, quality, and connectivity) and species-specific parameters (species selection based on their CS rates and habitat requirements for keystone species), must be analyzed while designing buildings for vegetation-based CS and HP.

**Keywords:** carbon sequestration; habitat provisioning; regenerative architecture; urban ecology; building-integrated vegetation; urban green spaces; expert survey

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## 1. Introduction

The concept of regenerative design, introduced by J. Lyle in 1994, is described as replacing linear throughput processes with closed-loop ones at source, consumption centers, and sinks [1]. Over the following decades, analogous concepts, such as cradle-to-cradle design [2], ecological design [3], ecosystem services analysis [4], and net-positive design [5] gained popularity. In the field of architecture and urban design, regenerative design, popularized by Reed in 2007 [6], aimed to shift the paradigm from sustainable development to the creation of socio-ecological health and restoration of living systems rather than the depletion of life support systems [6–8]. These regenerative design theories and frameworks revolutionized leading edge design thinking, calling upon the built environment to co-evolve with nature while challenging 'green' and 'sustainable' design goals characterized as doing less harm or having a neutral impact. Pedersen Zari [4] linked regenerative design to ecosystem services provisioning as a way to practically emulate ecosystem functions through architectural and urban design. This research builds upon that conception of regenerative design. It investigates how architectural design for carbon sequestration combined with design for habitat provisioning can contribute to reducing or potentially reversing built environment-related impacts and causes of climate change and biodiversity loss.

The interlinked issues of climate change and biodiversity loss are perhaps the most urgent global issues humans must grapple with. In this era of climate change, there are significant impacts on biodiversity and habitats, leading to biodiversity loss and degraded habitats. Moreover, biodiversity loss further contributes to climate change at macro and micro levels [9]. According to the Intergovernmental Panel on Climate Change, negative impacts on biodiversity (species loss and extinction) increase with the temperature rise [10]. The expansion of the urban built environment contributes significantly to climate change and biodiversity loss. Thus, the urban built environment, climate change, and biodiversity nexus create a positive feedback loop of cause and effect, meaning that increased climate change causes increased biodiversity loss and vice versa [11,12].

An extensive literature review indicates that concurrently designing for carbon sequestration and habitat provisioning can contribute to regenerating and revitalizing ecosystems by reducing climate change impacts or increasing resilience to them, and creating symbiotic urban co-habitation opportunities that cater to the needs of both humans and other living species [9,13–17]. There is also unambiguous evidence that this ecosystem-based approach can contribute to improving human health and well-being directly through improved ecosystem health [18–20]. The most common architecture-centric manifestation of a carbon/habitat design approach is design that creates building-integrated vegetation and green areas on and around buildings, which are suitable for both carbon sequestration and habitat provisioning. Figure 1 illustrates common strategies for the inclusion of vegetation on and around buildings. Several studies highlighted the psychological benefits of including green spaces in the urban built environment, such as mental health benefits for children [21], improved physical health of urban residents [22], faster recovery of patients with a view of greenery [23], and improved productivity in the workplace [24]. A study by Fuller et al. [25] indicated that with the increase in biodiversity in urban green spaces, the psychological benefits proportionately increase.

**Figure 1.** Common strategies to include vegetation on and around buildings. Image source: Bosco Verticale, CC BY-SA 2.0 (**left**), Green Wall, CC BY-SA 2.0 (**top right**), Gardens by the Bay, Singapore, and CC BY-SA 2.0 (**bottom right**).

Vegetation-based carbon sequestration is a natural ecological process that actively removes carbon from the atmosphere as vegetation grows. This process can be anthropogenically driven if strategic planting of biomass occurs. Concerning built environment design, this can happen by employing vegetation in, on, and around buildings [26,27]. Habitat provisioning through vegetation, is the provision of the resources and environmental conditions (such as food and shelter) that particular species needs to survive and thrive [4,28]. Considering the potential carbon sequestration and habitat provisioning benefits of building-integrated vegetation, an extensive literature study was conducted to determine how best to concurrently integrate these ecosystem services into building design. To support, expand, and test these findings, research that establishes and integrates expert opinion was essential. This research, therefore, aims to provide a deeper understanding of the most appropriate carbon sequestration and habitat provisioning strategies and methodological frameworks through utilizing exploratory questionnaire-based research targeting experts in this field. A survey facilitates a broader coverage of information on different topics from an extensive data set in a given timeframe [29]. Therefore, a questionnaire-based survey was preferred for data collection in order to:

- understand the opinion of different experts regarding carbon sequestration and habitat provisioning strategies and methodologies; and
- identify and describe the variability in opinions between built environment professionals and environmental specialists (including researchers) for all sets of inquiries.

This study was conducted to gather a range of data currently unavailable in the literature, i.e., experts' perspectives on carbon sequestration and habitat provisioning through building design based on their practical experiences and current trends. However, this research has some limitations. This kind of work necessarily is very site-specific because of local ecology, local climatic conditions, and climate change impacts. For example, the selection of specific plants is very site-specific. This means there may be vastly different opinions between respondents in different cultural, climatic, and contextual conditions. The geographical and cultural context of the respondents are extremely important aspects; however, understanding this in-depth is beyond the scope of this research. The intention of this survey was to understand international expertise broadly around these topics. The following sections provide an overview of the survey design, responses, recommendations, and findings.

## 2. Materials and Methods

### 2.1. Questionnaire Design

A two-stage approach was developed to prepare the questionnaire. Firstly, an extensive literature review was conducted. This literature review is expanded upon in other publications [12,27,28,30]. The 352 papers that were used in the literature review can be accessed by contacting the corresponding author. Key areas that came out of the literature review related to carbon sequestration and habitat provisioning were: benefits, barriers and solutions, data gathering approaches, strategies, parameters/indicators, frameworks to quantify, and performance indicators to measure the success of these projects. A conceptual framework was prepared from these key areas, deduced from the evidence-based design literature, to illustrate how to implement carbon sequestration and habitat provisioning strategies through building design (Figure 2).

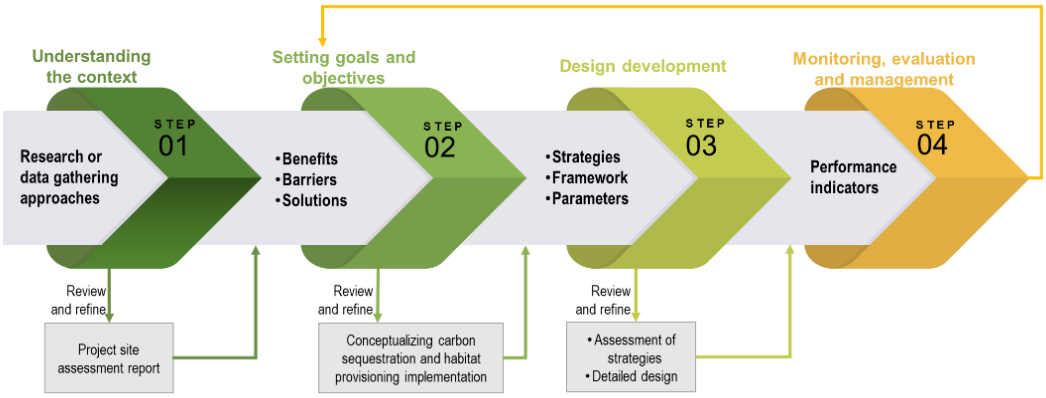


**Figure 2.** A conceptual framework for implementing carbon sequestration and habitat provisioning strategies through building design.

Secondly, a survey was developed, where investigative questions were aligned with the conceptual framework in order to test and refine it.

The conceptual framework was comprised of four simple steps.

- Step 1: Understanding the context: this step identifies the research or data gathering approaches to implement carbon sequestration and habitat provisioning strategies through building design. The result of this stage provides the project site assessment report that is utilized in the next step to set goals and objectives.
- Step 2: Setting goals and objectives: this step includes (a) identifying the benefits that these carbon sequestration and habitat provisioning strategies provide, (b) identifying the barriers to implementing carbon sequestration and habitat provisioning strategies, and (c) identifying solutions to overcome those barriers. As a result, a concept is prepared for implementing the carbon sequestration and habitat provisioning strategies.
- Step 3: Design development: this step includes (a) identifying the strategies aiming to increase carbon sequestration rates and biodiversity levels, (b) identifying how to quantify these strategies, and (c) identifying different parameters/factors to assess the efficiency of building-related carbon sequestration or habitat provisioning strategies during the design phase. This step results in preparing a detailed design after the assessment of strategies.
- Step 4: Monitoring, evaluation, and management: this step includes identifying the performance indicators that measure the success of the project post-construction. This last step provides short-, medium-, and long-term management plans, taking into account the performance assessment of carbon-responsive biodiverse development.

The survey was made up of 30 questions, comprising both closed (exploratory) and open-ended (explanatory) types of questions, as detailed by Dilman [31] and Fink [32]. It was organized into four sections:

Section A included questions related to the respondent's occupation, experience, and location of their projects.

Sections B and C were for carbon sequestration and habitat provisioning, respectively, covering the overall design inputs/requirements, strategies, framework, parameters, and performance indicators. Two types of questions were presented in these sections for each set of inquiries. These were:

a. Matrix questions: respondents had to select from options "not at all important" to "extremely important" in order to collect the *opinion* of all respondents on the subject matter.

b. Open-ended: These questions were added to collect any missing data from the list provided for design for carbon sequestration and habitat provisioning. The respondents could provide additions to the list. These questions provided *recommendations* from different experts on the subject matter.

Asking open-ended questions along with closed-ended ones can provide a higher degree of validity to the survey data [33].

Section D included questions related to the relationship between carbon sequestration and habitat provisioning. The first investigative question in this section was to determine the degree of agreement of the respondents (through a Likert-style 5-point rating scale: strongly disagree to strongly agree) on the co-benefits of providing habitat and sequestering carbon. The other investigative questions were related to the benefits of providing habitat provisioning and carbon sequestration strategies, barriers to implementing those strategies, and potential solutions to overcome those barriers in the form of list questions. This means the respondents had to select multiple/appropriate options from the list provided. The last question was open-ended, where respondents could provide recommendations or feedback on the survey.

### *2.2. Sampling Process*

A non-probability sampling technique was chosen because the samples/respondents were targeted internationally, and therefore it was not possible to construct a sampling frame [29]. This sampling technique allows selecting the sample/respondent purposively, i.e., working with small samples. Moreover, purposive sampling allows selecting cases that best answer the research questions and meet objectives focusing on non-statistical inferences [33]. For this purpose, homogeneous sampling was conducted, targeting built environment professionals and environmental scientists (including researchers) who worked on/researched sustainable/regenerative development.

Three techniques were applied to find relevant respondents for the survey, and subsequently, a list of contacts was prepared. First, a list of potential respondents was prepared according to their experience and contribution to sustainable/regenerative development after finding companies' websites and email addresses, and through searching professional social media sites such as LinkedIn. Second, a comprehensive search was conducted on scientific databases using a wide range of keywords to find relevant publications. Accordingly, emails were sent to the corresponding authors of relevant research-based papers published in journals of international repute. Third, a snowball sampling approach was followed to increase the number of respondents and reduce the possibility of missing potential respondents worldwide. In this snowball sampling approach, at the end of the questionnaire, respondents were asked to forward the questionnaire link to their contacts who might be able to contribute to this research.

### *2.3. Data Collection, Analysis, and Management*

Qualtrics was used as a survey tool to prepare the questionnaire and facilitate its distribution by generating the survey link. The questionnaire was designed as self-administered (i.e., to be completed by the respondents) and distributed electronically through email [29]. Following the preparation of a list of contacts of expert practitioners and researchers, approximately 250 invitations were sent to fill in the survey. Over three months, from 8 September 2021 to 8 December 2021, the online questionnaire was circulated to expert practitioners and researchers worldwide. A response rate of 32% was received (80 respondents). The survey was anonymous, and therefore, the threat of biased answering was reduced to get their genuine opinions [34].

The collected data were later imported into the Statistical Package for Social Sciences (SPSS) for analysis. SPSS is a tool for conducting statistical analysis and interpreting the results of the research [35]. Following the descriptive statistics and by screening the data manually, it was found that 24 respondents (out of 80) failed to complete Section B and onwards. Therefore, those responses were deleted from the analysis. A total of 56 respondents completed Section B and 100% of the survey. Therefore, the analysis was conducted for 56 responses. Furthermore, all questions were not mandatory to answer, and therefore, the number of respondents differed for each inquiry.

The analysis methods implemented for each section are described below:

Section A included category questions to determine the respondents' occupation and experience and an open-ended question about the location of their projects. Category questions are designed to collect attributes of the respondents where the respondent can select only one option among the available options [29]. For these questions, a simple analysis of counting the number of occurrences in each category and then converting them into percentages was performed. Findings from the open-ended question related to the locations of the respondents' projects were mapped.

Section B, C, and D: the percentage was calculated based on the number of occurrences for each rating, and pie charts were prepared to represent the data. The analysis methods for the closed and open-ended questions are described below:

a. Likert scale rating questions (opinion data): collective and comparative analyses were performed for both of these types of questions. Descriptive statistics on total percentages collectively for both groups and comparisons of the two groups (built environment professionals and environmental scientists, including researchers) were performed using SPSS. For the evaluation, cross-tabulations were performed for each type of question to compare the opinion of these two groups [29,31], and 100% stacked multiple bar charts were prepared for the two groups to represent and compare the percentage of responses.
b. Open-ended (recommendation data): The analysis of open-ended questions employed an approach that worked with qualitative methods by examining the texts and then identifying keywords in order to group the results. Repeated data were combined into one data set. Quotations from the respondents were used to support the interpretation of the results.

The following sections analyze the results of ten sets of inquiries for both carbon sequestration and habitat provisioning sections (i.e., Sections 3.2 and 3.3). For each set of inquiries, there are two questions, a closed-ended and an open-ended one, as described above and in the questionnaire design section. Sections 3.4.1 to 3.4.3 represent the analysis of closed-ended questions related to the relationship between carbon sequestration and habitat provisioning. The last question, which was open-ended, was analyzed in Section 3.4.4. The findings and recommendations from all the analyses are represented in Section 4.

## 3. Results

### *3.1. Experience*

The first question asked was about the current role and experience of the respondents. As a result, the respondents were divided into two groups:

- Group A (34 respondents): built environment professionals, including architects/landscape architects/urban planners/urban designers/developers/building scientists/building rating, regulation, or monitoring professionals
- Group B (22 respondents): environmental scientists/ecologists/climate scientists/biologists/researchers

It was reasonable to assume that these two groups may have different opinions on carbon sequestration and habitat provisioning implementation in building design because of their different expertise and experience. Analysis of the experts' background information revealed that the reliability and credibility of the study results are likely to be high because more than two-thirds of the respondents (68%) had more than 11 years of experience in their field.

The location of projects/research work was an open-ended question; the continent-wide distribution results are mapped and shown in Figure 3 below. A total of 32% of the respondents worked in Oceania, followed by 26% in Europe, 25% in Asia, and

15% in North America. A few respondents worked/are working on projects in South America (1%) and Africa (1%).

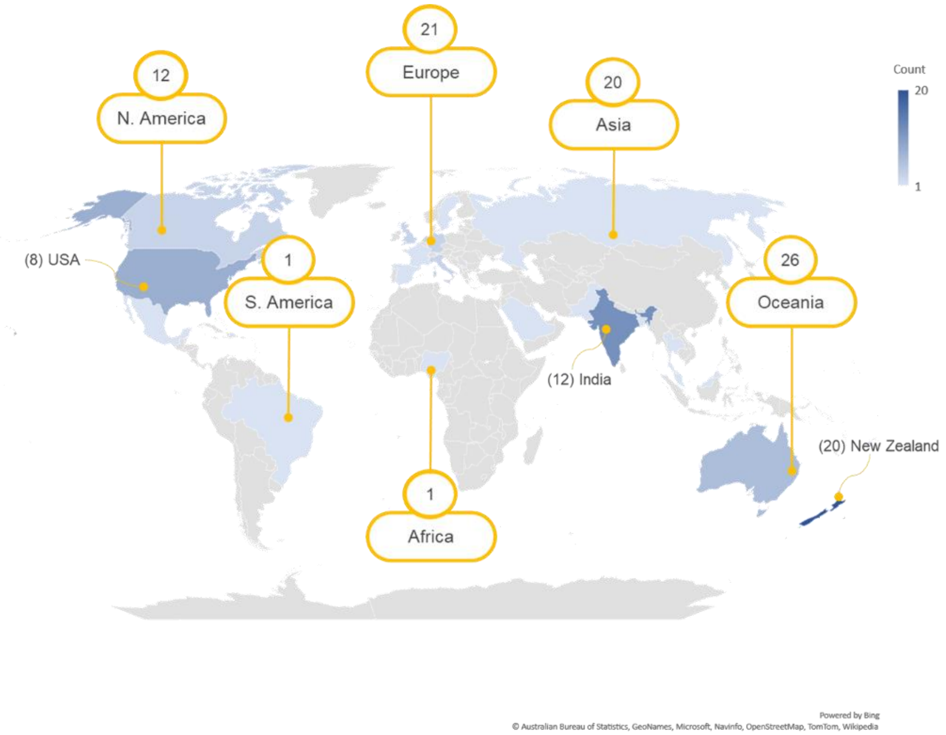


**Figure 3.** Location of respondents' projects/research work.

### 3.2. Carbon Sequestration

The next question was designed to ascertain how important the respondents think it is to consider carbon sequestration strategies in building design. A majority of the respondents (73%) think it is very important or extremely important, and only 10% think it is slightly important or not at all important (Figure 4).

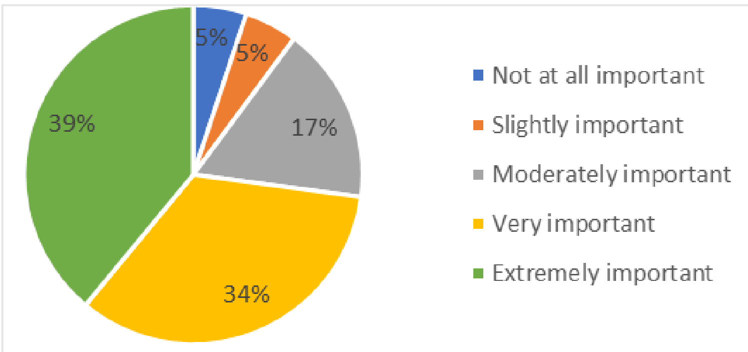


**Figure 4.** Opinion of respondents on how important they think it is to consider carbon sequestration strategies in building design.

#### 3.2.1. Research or Data Gathering Approaches when Considering Carbon Sequestration in Relation to Building Design

This set of questions provided opinions related to how important the respondents think the research or data gathering approaches in the list are, while considering carbon sequestration in relation to building design, and captured their recommendations for adding any missing data gathering approaches to the list. The list described here can be seen in Figure 5. Items are numbered 1 to 13.

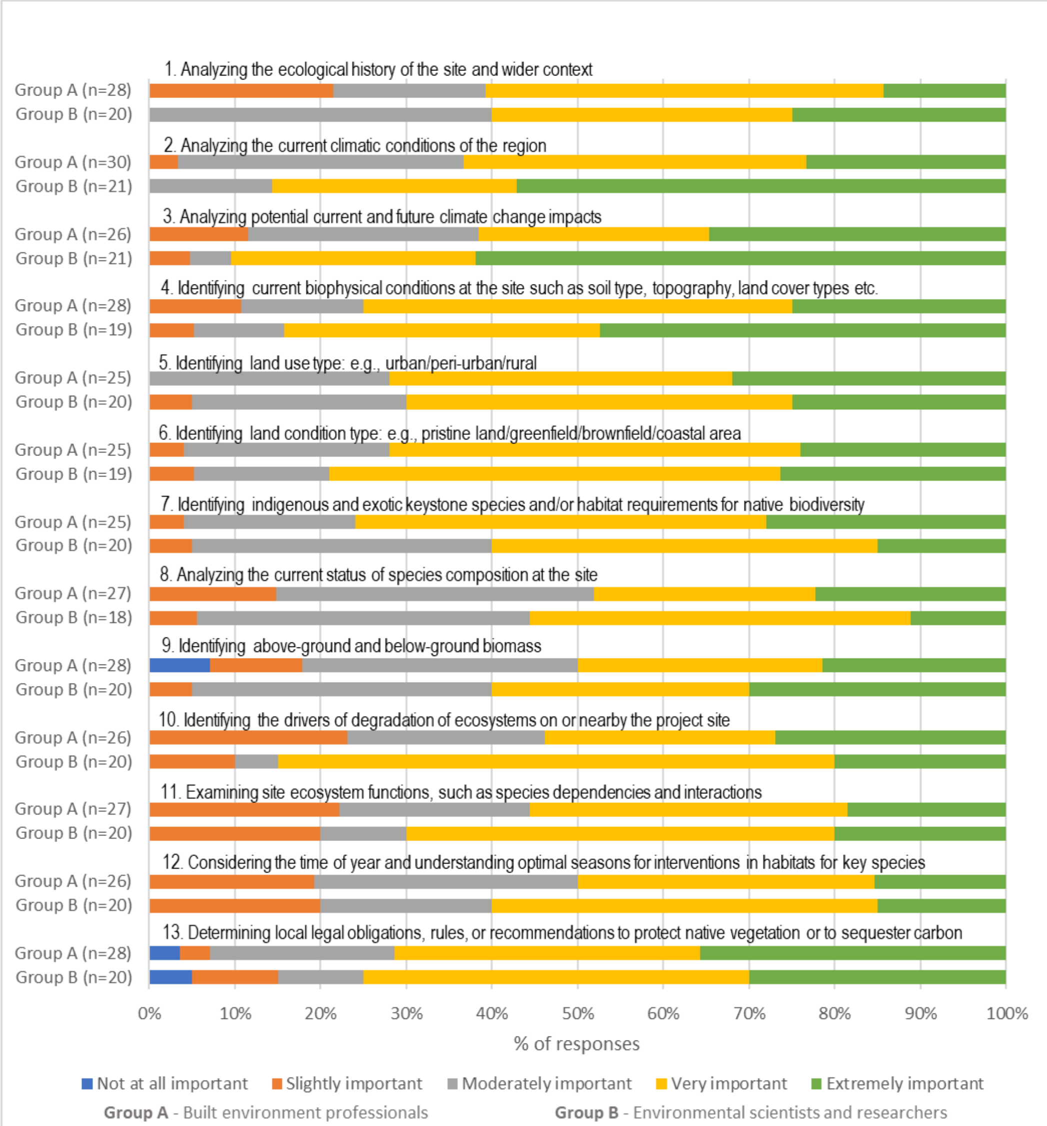


**Figure 5.** Research or data gathering approaches for carbon sequestration.

Figure 5 indicates the data presented in the form of 100% stacked multiple bar charts prepared after cross-tabulation, represented with five different colors for "not at all important" to the "extremely important" rating scale for both groups A and B. Overall, potential climate change impacts, analyzing current climatic conditions, and identifying current biophysical site conditions (i.e., 3, 2, and 4) were ranked as the top three most important data gathering approaches for initiating design for carbon sequestration. In contrast, considering the time of year/seasons, analyzing the current status of species composition and identifying above- and below-ground mass (i.e., 12, 8, and 9) were ranked as the three least important data gathering approaches. The multiple bar chart indicates a clear comparison of both groups' opinions. Environmental scientists and researchers have a strong positive opinion about understanding the climatic conditions, potential climate change impacts, identifying biophysical conditions of the site, and identifying drivers of degradation compared to the built environment professionals (i.e., 2, 3, 4, and 10). However, both groups, A and B, have a similar opinion on ranking the least important data gathering approaches (refer to preferences for 8, 9, 11, and 12 represented through multiple bar charts in Figure 5).

For the open-ended question, one of the respondents suggested that "carbon sequestration should be an added goal to biodiversity protection and restoration and not come ahead of it, or we will end up in a perverse incentive system". In this research, both carbon sequestration and habitat provisioning are simultaneously addressed through building-integrated vegetation and green spaces, and their synergies and trade-offs are considered while designing. Carbon-capturing and biodiversity-positive buildings can improve both ecological and human health and well-being [36]. Therefore, it is imperative that the incentive system, if provided, should include both benefits.

A few respondents suggested evaluating "embodied carbon emissions". It is important to note that carbon emissions reduction is still vital for achieving sustainability or regenerative targets, even if carbon capture strategies are adopted [37]. A few respondents suggested including "carbon sequestration through building materials (for example, timber)"; using building materials that store carbon is important and should be encouraged, but it is not the same as carbon sequestration, which is using the built environment to actively pull carbon out of the atmosphere through building-integrated vegetation [13,27,38].

### 3.2.2. Strategies to Increase Carbon Sequestration

This set of questions provided opinions relating to how important the respondents think the strategies in the list are, while considering carbon sequestration in relation to building design and gathered their recommendations for adding any missing strategies to the list. The list described here can be seen in Figure 6. Items are numbered 1 to 8.

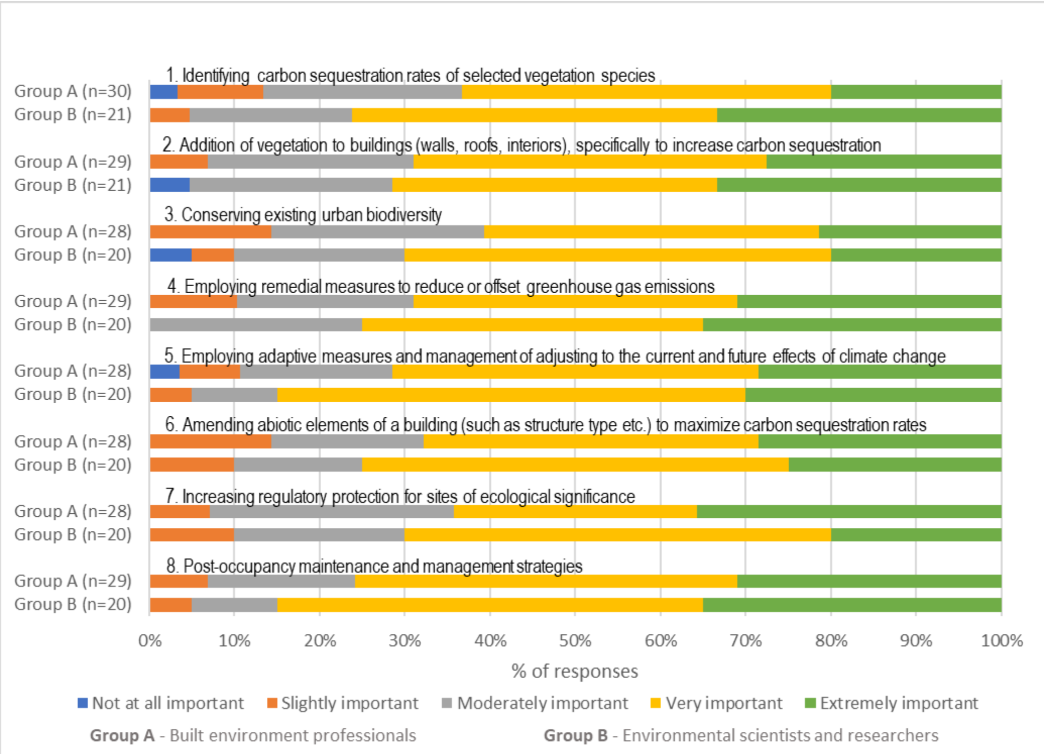


**Figure 6.** Strategies to increase carbon sequestration through building design.

Post-occupancy maintenance and management strategies, employing adaptive measures, and reducing or offsetting greenhouse gas emissions (i.e., 8, 5, and 4) were considered the most important strategies by both groups (Figure 6). However, there was a difference in opinion of both groups for strategy: identifying carbon sequestration rates of selected vegetation species (i.e., 1). Group A ranked this strategy as the least important (number 8, mean = 3.67), while group B ranked it as number 4 (mean = 4.05) compared to other strategies on the list. The literature study emphasized the importance of selecting vegetation species based on their carbon sequestration rates, which primarily vary due to different factors, such as species composition, life span, maintenance, decomposition, and energy conservation [39]. Perhaps a coordinated approach by employing ecologists at the pre-design phase to work collectively with built environment professionals could help to select appropriate vegetation species.

For the open-ended question in this section, one of the respondents suggested including "using different materials (mycelium) and fabrics (algae)…for carbon absorption". Another respondent suggested "low carbon impact materials". This research focuses explicitly on vegetation-based carbon sequestration. Therefore, considering how materials store carbon during design development is encouraged, but its beneficial impacts could not be evaluated within this research.

3.2.3. Parameters to Assess Building-Related Carbon Sequestration Strategies during the Design Phase

This set of questions provided opinions related to how important the respondents think the parameters in the list are, for assessing building-related carbon sequestration strategies during the design phase and gathered recommendations for adding any missing parameters to the list. The list described here can be seen in Figure 7. Items are numbered 1 to 9.

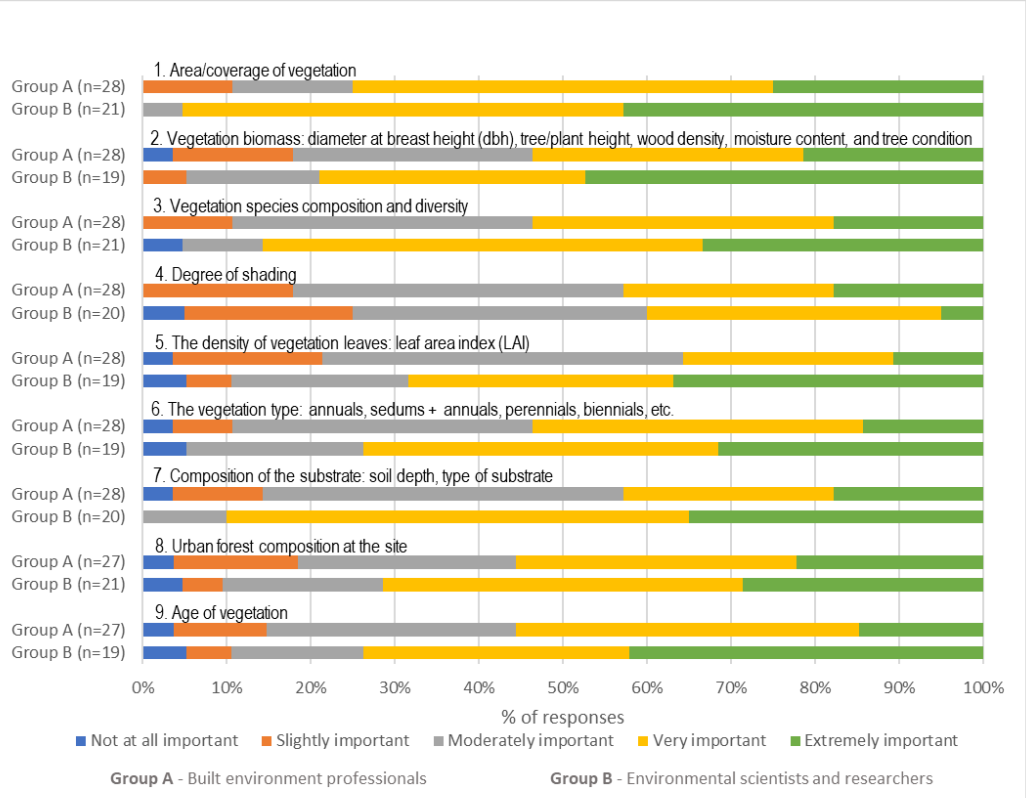


**Figure 7.** Parameters for assessing building-related carbon sequestration strategies.

There was an evident misalignment in the two groups of respondents' opinions (Figure 7). More than 70% of environmental scientists and researchers ranked all the parameters in the list (except the degree of shading) as very important and extremely important. In contrast, more than 70% of the built environmental professionals ranked only area/vegetation coverage (i.e., 1) as very important and extremely important. This was an expected response because, through the literature of case studies of the built environment, it was observed that only the area of vegetation was measured to calculate the amount of yearly carbon sequestered at a particular site [37,40]. However, the literature also suggests that carbon sequestration dynamics must be considered while aiming to increase carbon sequestration rates [41–43]. For example, mature trees store more carbon (but sequester less carbon) compared to young trees [44].

For the open-ended question in this section, one of the respondents recommended including "adequate soil, light, and irrigation (from built-in rainwater supply not dependent on people)". Identifying biophysical conditions are covered under the data gathering strategies. However, the availability of adequate soil, light, and irrigation are some of the parameters that are proportionally related to the amount of carbon sequestered [45]. Moreover, there was a suggestion to assess the "hardiness of vegetation (can they withstand high wind loads, for example)". This is an essential factor and must be considered when designing climate-responsive buildings and considering the resilience of vegetation to withstand extreme weather conditions [46,47]. Therefore, these items will be added to the list of parameters.

#### 3.2.4. Frameworks for Quantifying Carbon Sequestration Rates

This set of questions provided opinions related to how important the respondents think the frameworks in the list are, for quantifying carbon sequestration rates at a building scale and gathered recommendations for adding any missing frameworks to the list. The list described here can be seen in Figure 8. Items are numbered 1 to 3.

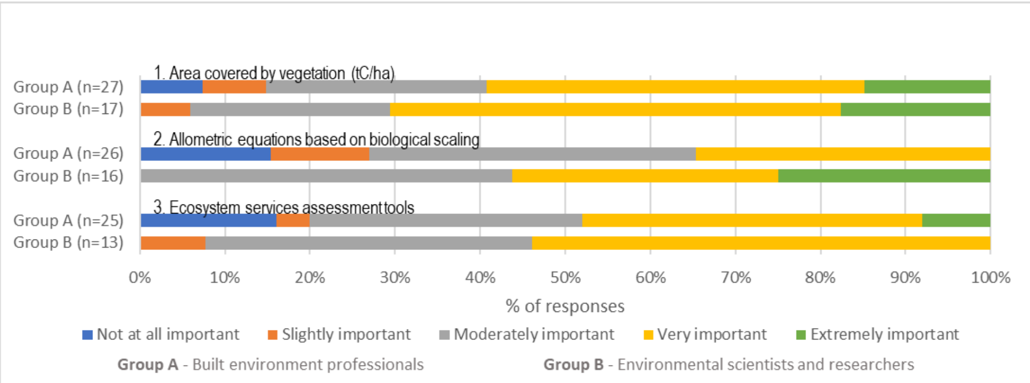


**Figure 8.** Frameworks for quantifying carbon sequestration rates.

Both groups unanimously responded to the most important framework, which was the area covered by vegetation (Figure 8). The concept of integrating carbon sequestration strategies into building design is new and evolving, and therefore, there are limited available methods to quantify carbon sequestration rates at the building scale [37,41].

When asked through the open-ended question in this section, one respondent commented, "we calculate the area covered by vegetation for urban agriculture requirements for the Living Building Challenge; we do not really do it for carbon sequestration reasons. This could be suggested as an improvement to the Living Building Challenge, which continually evolves" [48]. It is interesting to note that respondents think there is a need to improve existing building rating tools to include carbon sequestration. One of the respondents recommended "measuring soil carbon". It is essential to evaluate this because, according to Zirkle et al. [41], trees store carbon mostly above ground in the wood, and grassed areas store most of the carbon below ground in the soil. Although beyond the scope of this research, investigating such methodologies might be useful for building rating tool additions.

#### 3.2.5. Performance Indicators for Assessing the Success of Building-Related Carbon Sequestration Strategies Post-Construction

This set of questions provided opinions related to how important the respondents think the performance indicators in the list are, for assessing the success of building-related carbon sequestration strategies post-construction and gathered recommendations for adding any missing performance indicators to the list. The list described here can be seen in Figure 9. Items are numbered 1 to 3.

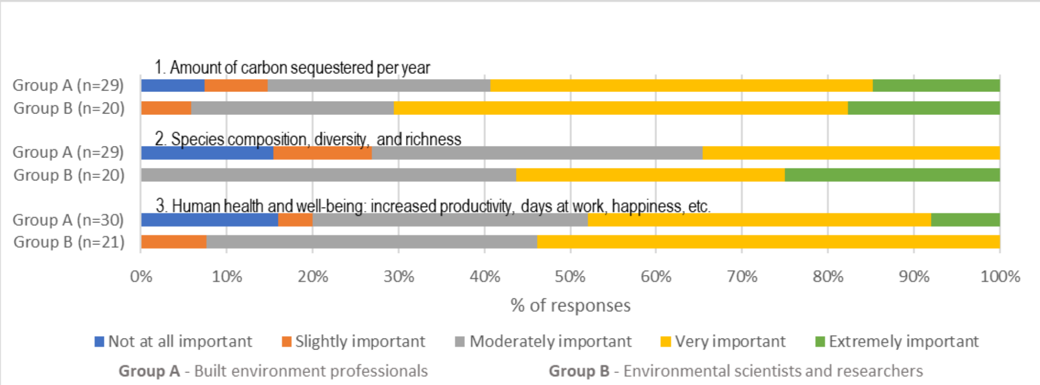


**Figure 9.** Performance indicators for assessing the success of building-related carbon sequestration strategies post-construction.

The amount of carbon sequestered per year (i.e., 1) was considered the most important performance indicator to measure the success of the project. The biodiversity and human well-being indicators were added to the list (see Figure 9) to investigate the respondent's point of view on the overall positive impacts of carbon sequestration, i.e., whether they think about the amount of carbon sequestered only or the overall benefits of providing building-integrated vegetation.

For the open-ended question in this section, one respondent suggested addressing the "survivability of vegetation", which is important to monitor post-construction and will be included in the above list. Another respondent advised assessing "benefits to humans beyond the site or ownership (not just occupants)". The overall benefits of carbon sequestration design are part of step 2 of the conceptual framework (Figure 2), and their monitoring and management will be included in this list. One of the respondents commented, "human health and well-being is not assessed in relation to carbon sequestration but in relation to Place Petal and Equity Petal Imperatives for the Living Building Challenge". The Living Building Challenge accounts for the "total embodied carbon emissions (tCO2e) from construction and the utilization of carbon-sequestering material to achieve net-positive carbon" [48]. However, achieving net-positive carbon building does not necessarily have to be limited to the use of materials that store carbon; rather, it needs to include the other strategies of active carbon sequestration (e.g., living vegetation-based), and the credits should be awarded according to their performance [37,49].

### *3.3. Habitat Provisioning*

The first question in the section related to habitat provisioning was designed to gain an understanding of respondents' thinking related to the importance of considering urban biodiversity/habitat provisioning strategies through building design. A majority of the respondents (78%) rated it very important and extremely important, and only 4% rated it as slightly important or not at all important (Figure 10).

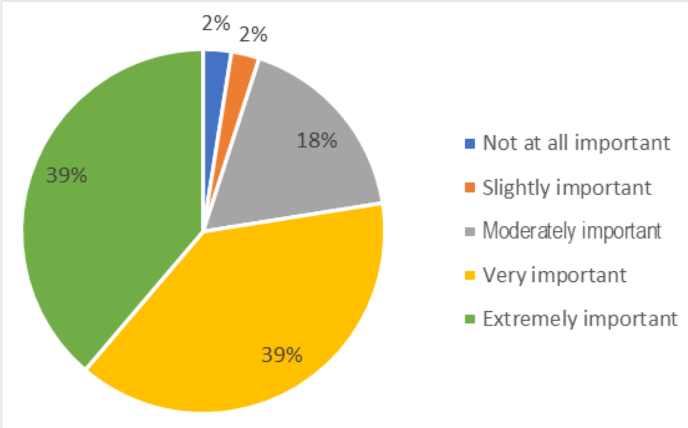


**Figure 10.** Opinion of respondents on how important they think it is to consider urban biodiversity/habitat provisioning strategies in building design.

3.3.1. Research or Data Gathering Approaches when Considering Urban biodiversity and Habitat Provisioning in Relation to Building Design

This set of questions provided opinions related to how important the respondents think the research or data gathering approaches in the list are, while considering urban biodiversity/habitat provisioning in relation to building design and captured recommendations for adding any missing data gathering approaches to the list. The list described here can be seen in Figure 11. Items are numbered 1 to 12.

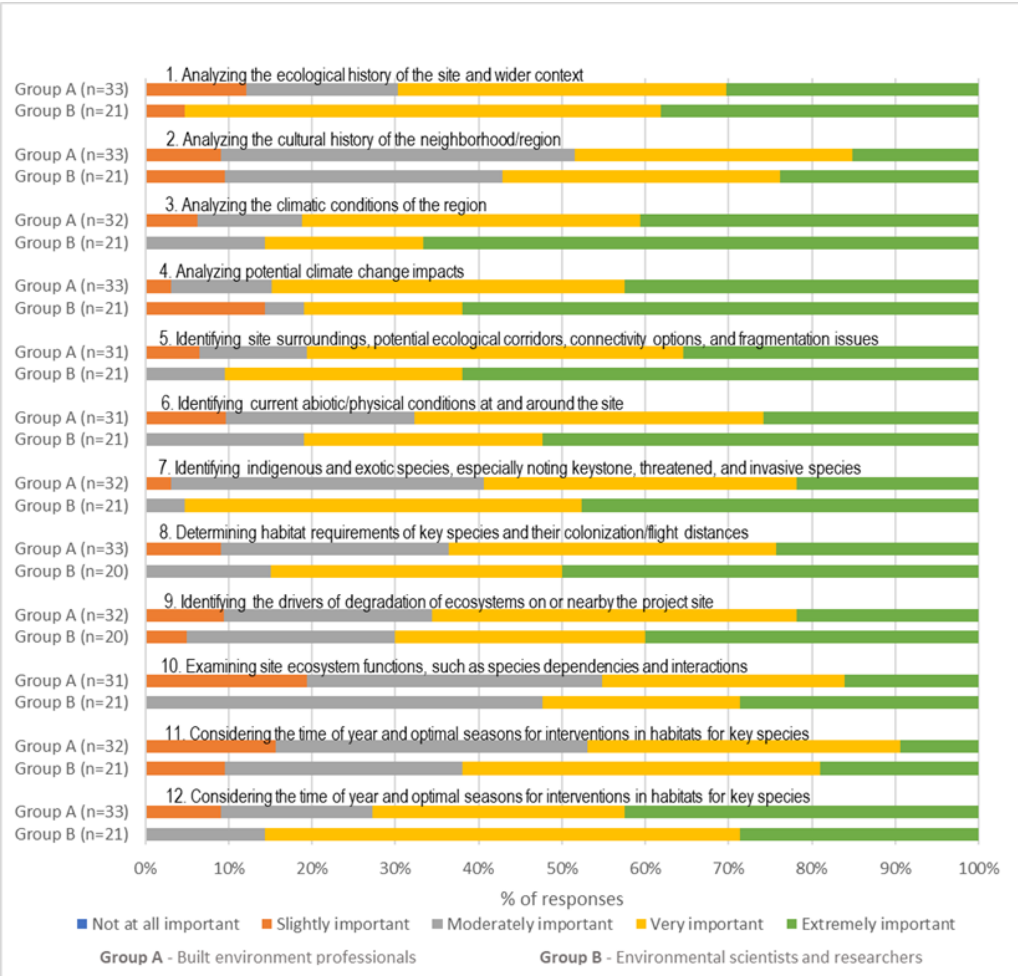


**Figure 11.** Research or data gathering approaches for habitat provisioning.

The three most important data gathering approaches ranked by respondents were analyzing the climatic conditions, identifying site surroundings, and analyzing potential climate change impacts (i.e., 3, 5, and 4). Moreover, both groups ranked considering the time of year/season, examining site ecosystem functions, and analyzing cultural history (i.e., 10, 11, and 2) as less important than other data gathering approaches mentioned in the list. Intriguingly, in the literature, culturally responsive architecture is considered essential for rebuilding the interrelations between community and sustainability, where the focus is on enhancing the quality of life [50].

The data presented in the form of multiple bar charts give a comparison of the two groups of respondents' opinions. Environmental scientists and researchers have strong opinions about the importance of understanding the climatic and ecological contexts prior to design compared to the built environment professionals, which is evident in the choice of the two groups selecting the "extremely important" option for 3, 4, 5, 6, 7, 8, and 9 presented in Figure 11. The major visible difference (35%) was the opinion of the two groups related to identifying indigenous and exotic species, where group B of environmental scientists and researchers thought of it as more important compared to group A of built environmental professionals.

For the open-ended question in this section, respondents suggested including several data gathering approaches already covered in the list, suggesting that details about what each approach means and is inclusive of will be important in future iterations of the framework of designs for habitat provisioning, particularly for built environment professionals. Recommendations, such as "food-webs/trophic complexity of community structure", "plant-animal interactions", "nutrient cycling and hydrology", and "connectivity of external exchanges" will be included under examining site ecosystem functions [51,52]. Suggestions, such as "environmental pollution (air, water, soil, noise, light), "potential risks associated with zoonotic diseases", and "engaging with biologists and experts", will be included in future lists of data gathering approaches. One respondent suggested including "quantifying/analyzing the ecological, environmental, social, cultural impacts in monetary terms". While beyond the scope of this research, this could be a topic for future research.

#### 3.3.2. Strategies to Increase Urban Biodiversity/Habitat Provisioning

This set of questions provided opinions related to how important the respondents think the strategies in the list are, while considering urban biodiversity/habitat provisioning in relation to building design and gathered recommendations for adding any missing strategies to the list. The list described here can be seen in Figure 12. Items are numbered 1 to 12.

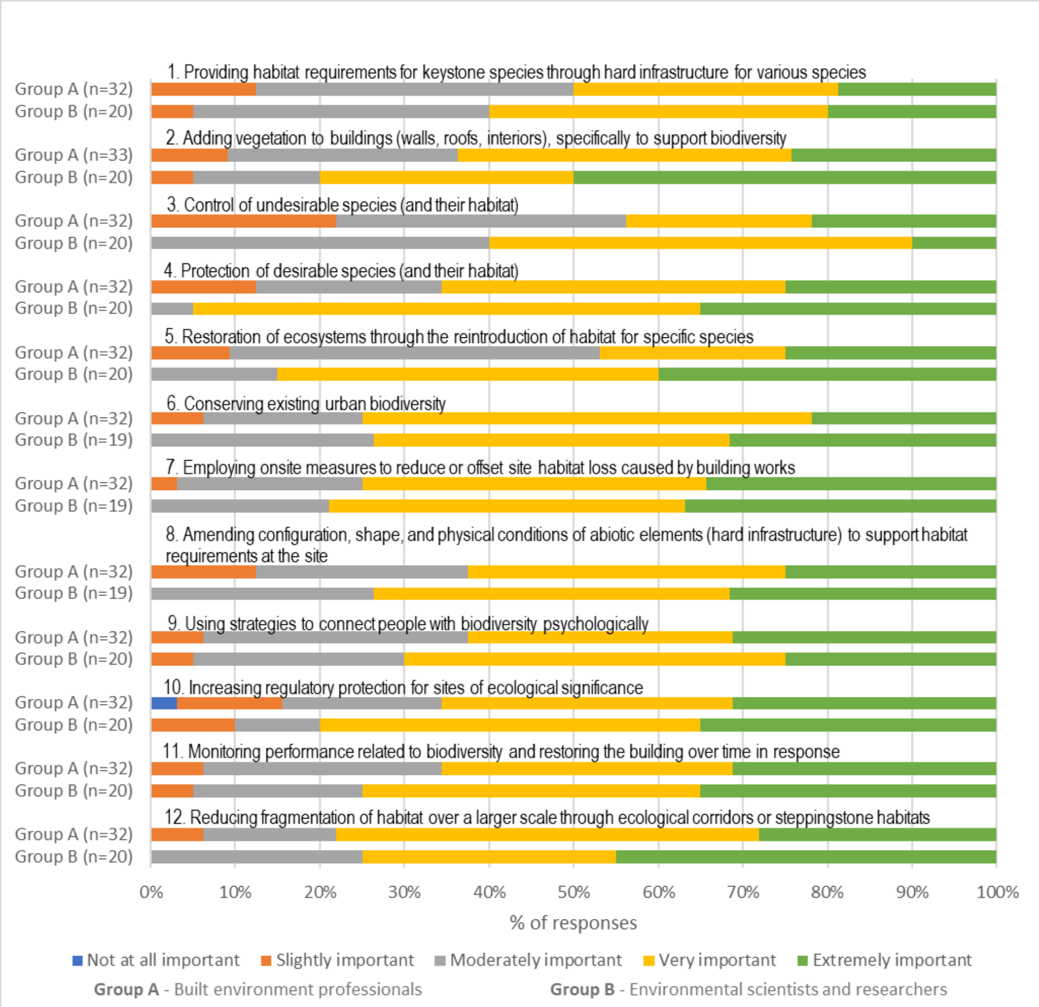


**Figure 12.** Strategies to increase urban biodiversity or habitat provisioning through building design.

According to environmental scientists and researchers, the three most important strategies were the protection of desirable species, restoration of ecosystems through the reintroduction of habitats and adding vegetation to buildings, and increasing regulatory protection (i.e., 4, 5, and 2—rated by more than 80% as very/extremely important). In contrast, built environment professionals gave lesser ratings to these strategies (Figure 12). According to built environment professionals, the most important strategies were employing onsite measures to reduce or offset site habitat loss caused by building works, reducing fragmentation, and conserving urban biodiversity (i.e., 7, 12, and 6—rated by more than 75% as very/extremely important). Both groups rated control of undesirable species and providing habitat requirements for keystone species (i.e., 3 and 1) as less important strategies than others on the list. Keystone species are the species that have a large effect on aspects of ecosystem functioning, meaning that managing these species can support the co-existence of other species in that community or the ecosystem [53,54]. The literature emphasizes that an approach to restoring an ecosystem that encourages the protection of keystone species by providing their habitat requirements can positively contribute to habitat conservation and, concurrently, biodiversity enhancement [55].

For the open-ended question in this section, one of the respondents suggested considering "multifunctional design to increase the ratio of ecological space to human space" and "means to allow nature corridors at open ground level through the building". One respondent suggested including "basic green design principles like wind tunnel effects, noise, shade, reflective surfaces, etc. that impact microclimates for animals and people". These strategies are important and must be considered while designing [56]. Therefore, these strategies will be added to the list. One of the respondents suggested having a "maintenance plan", which is essential and will be added to the monitoring performance strategy (i.e., 11). Another respondent commented on monitoring performance as "very difficult to do interventions in buildings or urban design interventions once they are built...not in control of the building professional/construction company/original owner…difficult to modify features of an already built area…and very expensive too….". Quantifying biodiversity levels and predicting variations is of high importance for biodiversity management and policy efforts [57]. Moreover, monitoring performance indicators over time to analyze the condition, state, and trends of biodiversity is essential to achieving regenerative goals [58].

#### 3.3.3. Parameters to Assess Building-Related Urban Biodiversity or Habitat Provisioning Strategies during the Design Phase

This set of questions provided opinions related to how important the respondents think the parameters in the list are, to assessing building-related urban biodiversity or habitat provisioning strategies during the design phase and gathered recommendations for adding any missing parameters to the list. The list described here can be seen in Figure 13. Items are numbered 1 to 10.

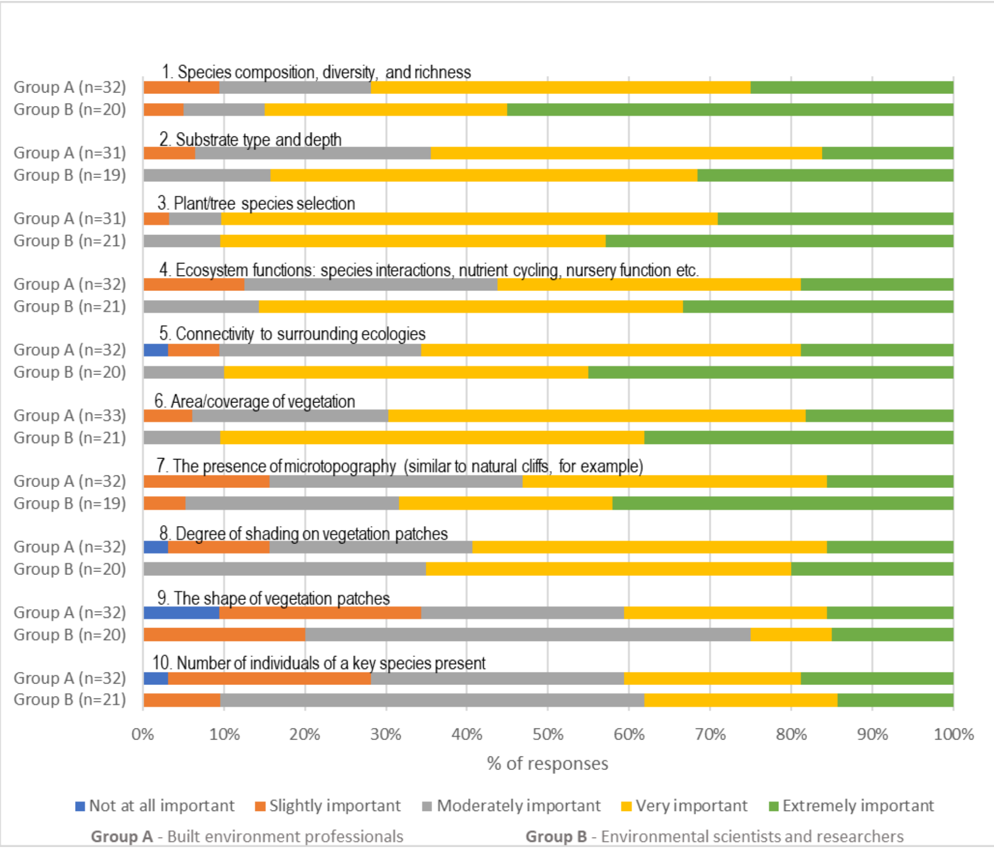


**Figure 13.** Parameters for assessing building-related habitat provisioning strategies.

The three most important strategies ranked by respondents were: plant/tree species selection, species composition, diversity and richness, and area/coverage of vegetation (i.e., 3, 1, and 6). Unanimously, the less important strategies selected by both groups were the number of individuals of key species present and the shape of vegetation patches (i.e., 10 and 9). According to environmental scientists and researchers, the most important parameter (rating 1, mean = 4.35) was connectivity to surrounding ecologies (i.e., 5). However, the built environment professionals gave a lesser rating to this parameter (rating 5, mean = 3.72). A difference in % of responses related to selecting the category 'extremely important' was quite high for group B compared to group A (Figure 13), which is evident for the parameters listed from 1 to 7.

For the open-ended question, one of the respondents recommended including "patch size and functional connectivity". A few of the respondents suggested considering "the role of species selection in relation to the ecotone or area" and "select the plants based on a study of their $CO_2$ capture capacity as a function of time"; these are important and will be included under plant/tree species selection. A few respondents commented, "shading should just be used to inform the species selection" and that "shape of vegetation patches and degree of shading depends on appropriate species". However, in this context, the parameters degree of shading and shape of vegetation patches will be assessed to evaluate their impact on biodiversity levels, employing birds as primary indicators [59,60].

### 3.3.4. Frameworks for Quantifying Biodiversity Levels

This set of questions provided opinions related to how important the respondents think the frameworks in the list are, for quantifying biodiversity levels at a building scale and gathering recommendations for adding any missing framework to the list. The list described here can be seen in Figure 14. Items are numbered 1 to 7.

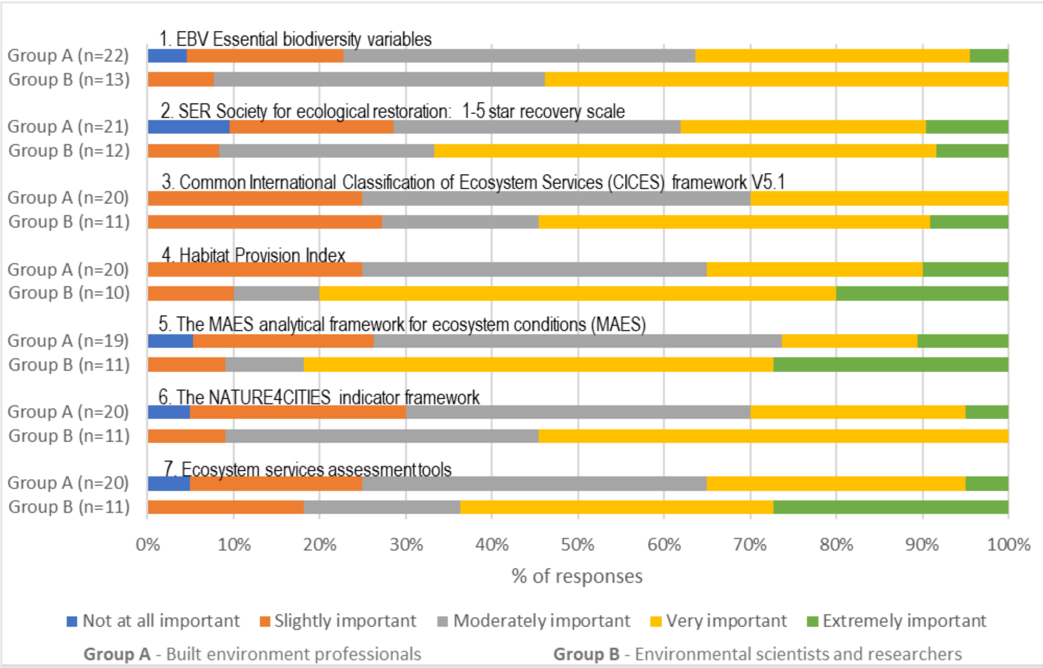


**Figure 14.** Frameworks for quantifying habitat provisioning rates.

As ranked by both groups collectively, the two most important frameworks were the habitat provision index and the MAES (Mapping and Assessment of Ecosystems and their Services) analytical framework. The data presented for this question indicated a similar result, as noted in the previous bar charts. Environmental scientists and researchers' ranking for individual options in the list was higher than built environment professionals. Perhaps integration of the ecosystem services concept into building design is relatively new to built environment professionals.

For the next open-ended question, one of the respondents recommended using "Environmental Impact Assessment (EIA)"; however, according to Slootweg [61], biodiversity considerations are inadequately addressed in the environmental impact assessment. There is a need for EIA enhancement that should lead to restored biodiversity, improved ecosystem services, increased security of that biodiversity, and enhanced areas for conservation [62]. Another respondent suggested "commonsense and knowledge of local flora, fauna, soil type, and microclimatic zones". Nevertheless, the biodiversity/habitat indicators are still required to measure the improved/degraded biodiversity levels compared to the baseline habitats, which need local biodiversity and ecosystem knowledge [57,63].

#### 3.3.5. Performance Indicators for Assessing the Success of Building-Related Urban Biodiversity or Habitat Provisioning Strategies Post-Construction

This set of questions provided opinions related to how important the respondents think the performance indicators in the list are, for assessing the success of building-related habitat provisioning strategies post-construction and gathered recommendations for adding any missing performance indicators to the list. The list described here can be seen in Figure 15. Items are numbered 1 to 4.

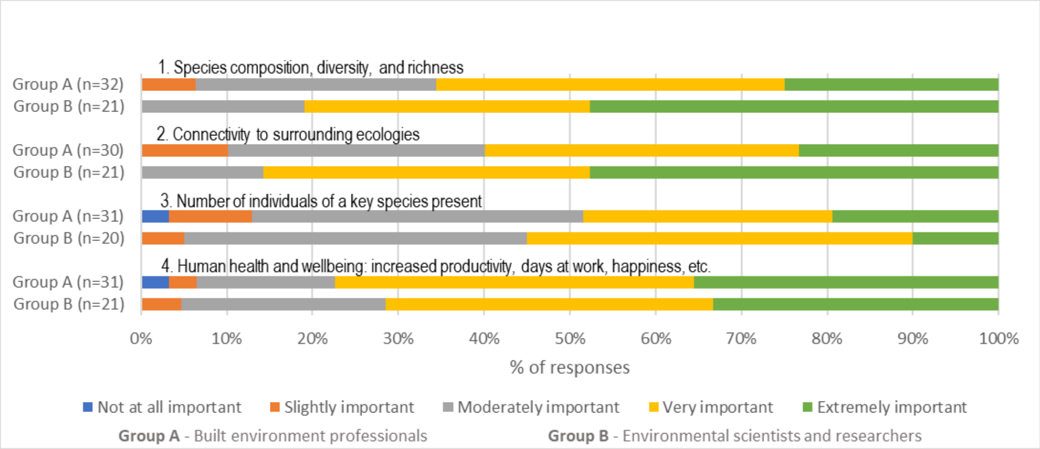


**Figure 15.** Performance indicators for assessing the success of building-related habitat provisioning strategies post-construction.

For this question, both the groups unanimously ranked the performance indicators; however, the percentage of responses differed (more for environmental scientists and researchers than built environment professionals). Human health and well-being was rated as the most important, and the number of individuals of a key species present was rated as the least important performance indicator (Figure 15).

Many respondents recommended including indicators to assess ecosystem functions/services (such as food availability for wildlife, air filtration, soil quality, predator-free habitat, land surface temperature/heat island effect, and water quality, availability, and filtration). There are multiple co-benefits that the ecosystem service of habitat provisioning provides because it supports most of the other ecosystem functions/services [64] and, therefore, will be included in the list of performance indicators. Other respondents suggested considering "evidence of key life stages (e.g., successful nesting/reproduction, not just presence/absence)", "percentage of each planted species surviving and thriving two summers after planting", "identification of new animal species or increased numbers in the new habitat not previously observed in this area", "number and abundance of threatened/protected species", and "canopy cover". All these indicators will be included under the category of species composition, diversity and richness, and the number of individuals of a key species present [52]. These indicators must be continually monitored after one year post-construction and for later milestones to assess the regeneration stage of the ecosystems [48].

### *3.4. Relationship between Carbon Sequestration and Habitat Provisioning*

The first question in this section was designed to ascertain respondents' degree of agreement on whether sequestering carbon and providing habitat through the same intervention, i.e., building-integrated vegetation, has co-benefits, and 84% of respondents indicated agreement, out of which 50% of the respondents strongly agreed (Figure 16). Positive responses from experts indicate the likely viability of integrating these two aspects of ecosystem service provisions into building design.

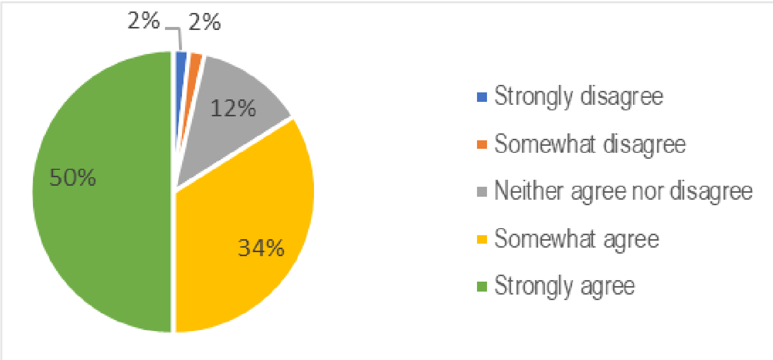


**Figure 16.** Co-benefits of sequestering carbon and providing habitat using vegetation in the built environment.

#### 3.4.1. Benefits of Implementing Carbon Sequestration and Habitat Provisioning Strategies

In the first question, the respondents were asked about the co-benefits of vegetation-based carbon sequestration and habitat provisioning. The list of benefits (see Figure 17) ranged from ecocentric/intrinsic benefits (such as improving ecological health) to anthropocentric benefits (such as human well-being). Environmental scientists and researchers were more inclined toward intrinsic benefits than built environment professionals (Figure 17). Intriguingly, built environmental professionals preferred ecological health and human well-being among the listed options.

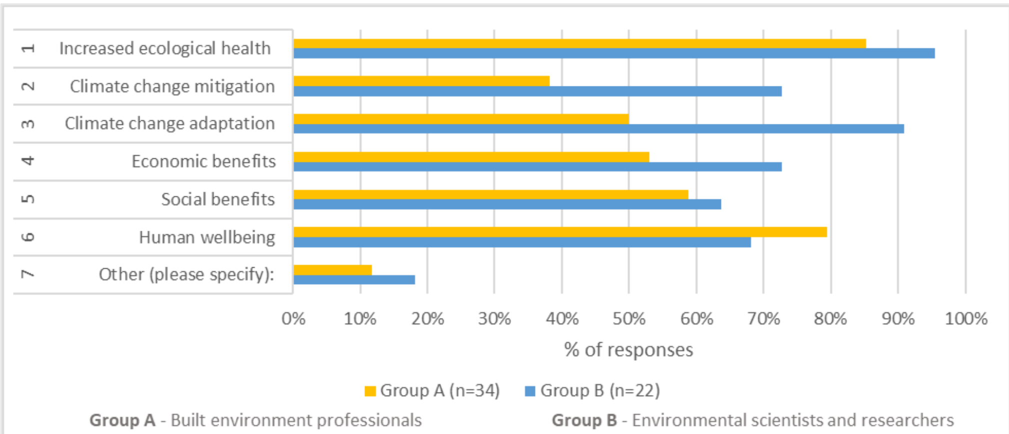


**Figure 17.** Co-benefits of sequestering carbon and providing habitat using vegetation in the built environment.

For the open-ended field in this section, the respondent's opinions vary from ecological (intrinsic), cultural (relational), and societal (utilitarian) benefits [65]. The respondents specified the ecocentric benefits as "increased contact with nature can result in increased value for nature and influence pro-environmental decisions and actions in those people", "habitat for other species", "increased biodiversity", "protection of ecology", and "generation of other ecosystem services, e.g., air quality improvement, temperature regulation, water filtration, etc.". Moreover, they suggested adding "cultural benefits (e.g., aesthetics)" and "amenities" to the list of co-benefits.

3.4.2. Barriers to Implementing Carbon Sequestration and Habitat Provisioning Strategies

In this question, respondents were asked to select barriers from the list provided (see Figure 18) to implementing carbon sequestration and habitat provisioning strategies through building design. Both the groups unanimously agreed that issues related to the client's project, scope, budget, and desired timelines are the major barriers (i.e., 2, selected by 70% of the respondents from group A and 85% from group B). Likewise, the lack of policy or regulations, lack of knowledge and skills, and provisioning in building norms (i.e., 8, 5, and 7) were other issues that were identified as other significant barriers to successfully delivering building design integrating carbon sequestration and habitat provisioning strategies (Figure 18).

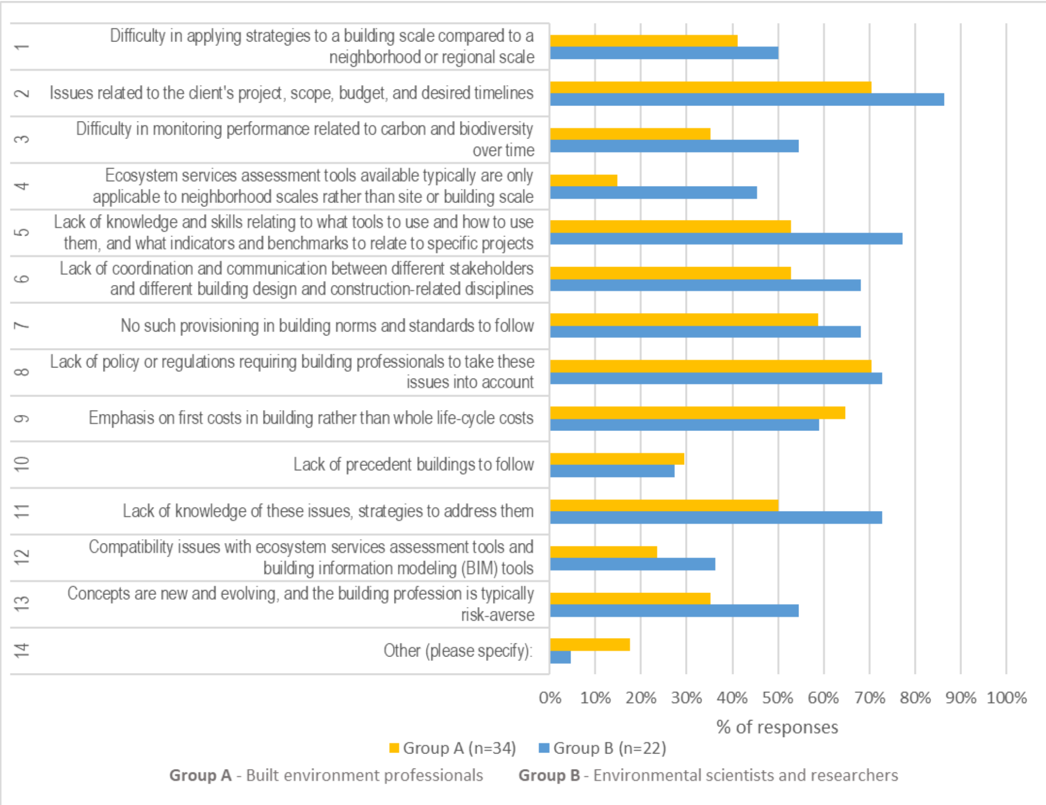


**Figure 18.** Barriers to implementing habitat provisioning and carbon sequestration strategies.

For the open-ended field in this section, the respondents specified additional barriers, such as "fear of promoting undesired species by implementing vegetation at buildings", "developers and designers, in their attempts to maximize site utilization, do not typically value the landscape and open space", "lack of long term strategy and vision", and "lack of engaging expertise in landscape architecture and ecology by architects who lead projects". In order to successfully implement carbon sequestration and habitat provisioning strategies, careful considerations must be given to overcome those barriers. Therefore, in the subsequent question, respondents were asked to select appropriate solutions to overcome barriers and were asked to suggest recommendations.

3.4.3. Requirements for Successfully Implementing Carbon Sequestration and Habitat Provisioning Strategies

As for the barriers, the potential solutions or the proposed requirements are categorized as technical (availability of tools, standards, technologies, and compatibility), organizational (addressing training needs), financial (fundraising and incentivizing), contextual (precedents, best practices, methodological framework, synergies and trade-offs, and database of strategies), and legal (policies, legal frameworks, and buildings norms). The literature also emphasizes that transdisciplinary research on the tools and methods, collaborating with multidisciplinary experts, and strengthening the conceptual foundation through spreading awareness and knowledge sharing are potential solutions to overcome the barriers [66,67]. The major barrier, i.e., the client's project, scope, budget, and desired timeline, could be addressed by linking the biodiversity and carbon considerations in policies and decision-making agendas, as well as incentivizing the projects that account for enhancing biodiversity and carbon-related outcomes [68–70].

According to environmental scientists and researchers, training professionals to improve their knowledge related to the indicators and parameters, and their skills related to what tools to use and how to use them (i.e., 3 and 2) are the best solutions to overcome the barriers identified previously (more than 80% selected) (Figure 19). In contrast, built environment professionals indicated that the requirements for successfully implementing carbon sequestration and habitat provisioning strategies are identifying best practice guides for typical building typologies/climates, linking these issues with decision-making agendas, and having legal frameworks for carbon sequestration and habitat provisioning considerations (i.e., 4, 11 and 12—more than 55% selected).

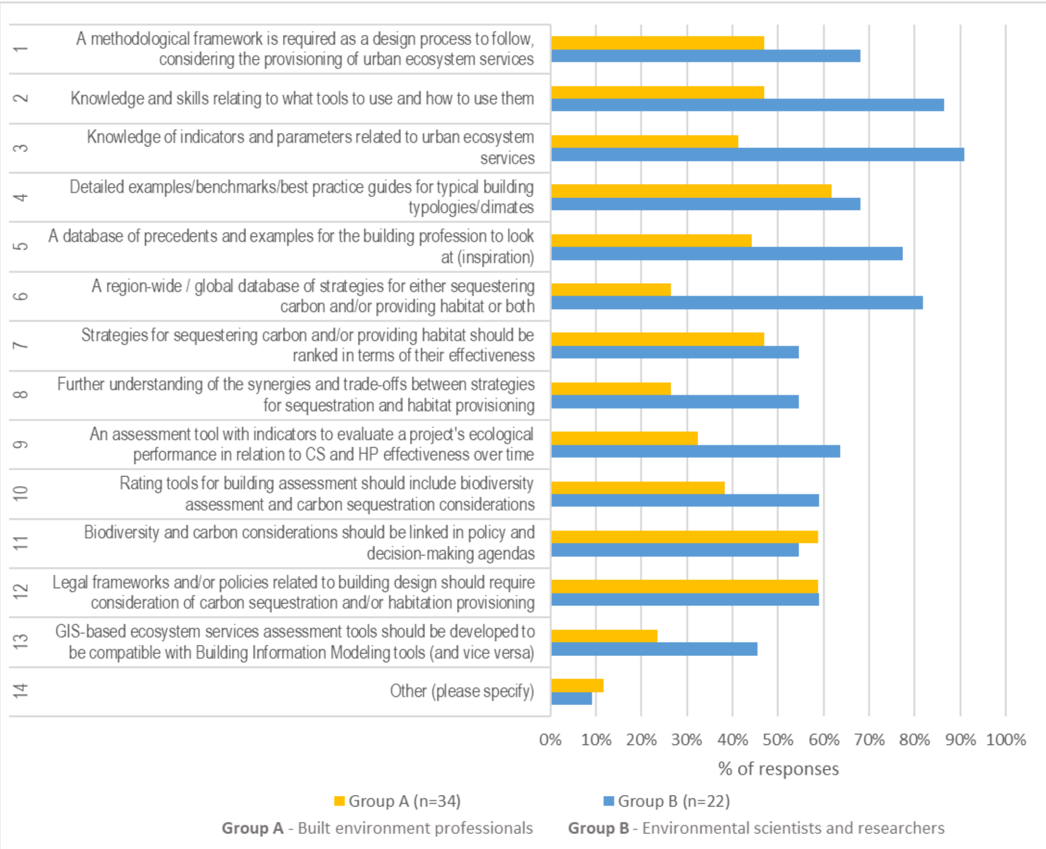


**Figure 19.** Solutions or requirements for successfully implementing habitat provisioning and carbon sequestration strategies.

For the open-ended field in this section, respondents specified among many suggestions that "cost-related factors", "creating the desire for planted buildings", "training in design thinking", and "cross-disciplinary work in this area" could be additional potential solutions to successfully implementing carbon sequestration and habitat provisioning strategies.

3.4.4. Additional Information or Recommendations

For this final open-ended question, themes and sub-themes were created from the recommendations received from the respondents, and a mind map was prepared using those themes (presented in Figure 20). Most of the respondents commented that this is a "new concept" in the field of built environment design and that more awareness should be spread, particularly among practicing architects/landscape designers and ecologists. This includes "government initiatives and building rating tools" to clarify and make accessible new concepts and "changing the architectural culture".

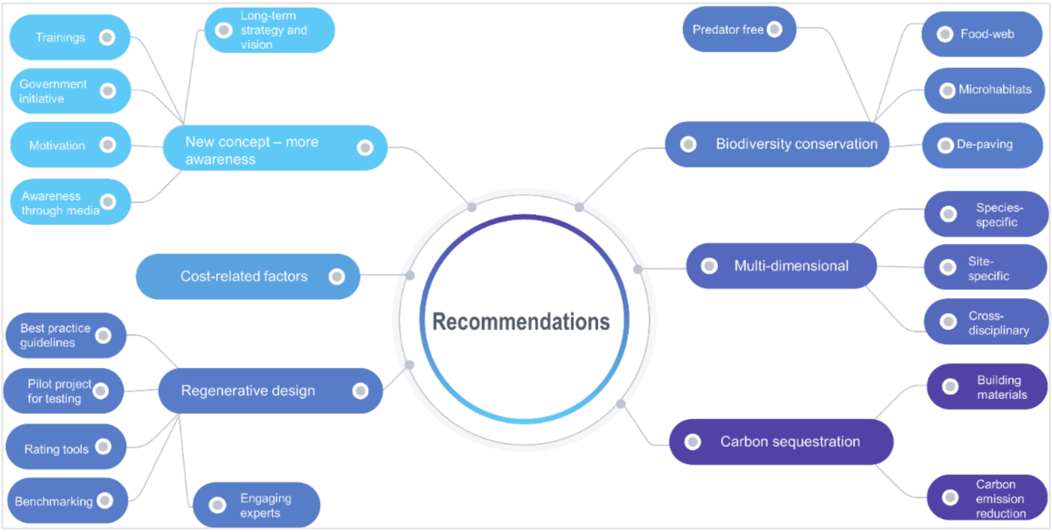


**Figure 20.** Additional information and recommendations.

According to another theme generated from the responses, a "holistic approach to regenerative design" is required to determine "best-practice guidelines and benchmarking for the new/retrofit projects". Biodiversity conservation and restoration in urban areas are "complex, multi-dimensional, and extremely species-specific". Therefore, careful consideration must be given to "multi-scale interventions (from buildings to regions)" to address biodiversity loss.

## 4. Discussion

This exploratory study was conducted with two main objectives: to understand expert opinion on the applicability of the conceptual framework derived from a systematic literature review and to identify any variability in opinions between the two groups surveyed, i.e., built environment professionals and environmental scientists and researchers. An overview was obtained from the survey data for carbon sequestration and habitat provisioning implementation through building design strategies as assessed by experts from two different groups. Collective and comparative analyses were conducted using descriptive statistics, majorly through cross-tabulation of data. Discussion of results is made based on the overall findings and the opinions and recommendations of respondents.

Although experts were from different countries and with diverse experiences, they had a fairly consistent consensus on ranking the different aspects of the lists prepared from the extensive literature review (see Figures 4–19). In addition, it is thought-provoking to observe that the two groups (i.e., built environment professionals—group A and environmental scientists and researchers—group B) had different opinions on almost all the aspects of the survey. The response rate and ranking provided by group B for different sets of inquiries were higher compared to group A. In a building design project, several contradictions may arise between experts and stakeholders that may influence decision-making and adoption (or rejection) of strategies to implement vegetation-based carbon sequestration and habitat provisioning. The regenerative design framework prepared by Cole et al. [71] suggests involving sustainable practices professionals and engaging ecologists, botanists, and hydrologists in the interdisciplinary design process. An integrated design approach involving all experts and stakeholders right from the pre-design stage may help minimize misunderstandings that were noted through the survey response.

The first and foremost finding for the carbon sequestration section was that awareness of this concept is variable. Some respondents stated that they do not know what carbon sequestration is. Some responses indicated that they confused carbon sequestration with carbon storage and with carbon emissions reduction. Therefore, increasing professionals' knowledge related to strategies, indicators, and parameters is likely to be a prerequisite to overcoming certain barriers to implementing carbon sequestration and habitat provisioning through building-integrated vegetation, as highlighted already [72].

The second finding was the emphasis by respondents on maintaining permanent vegetation on buildings in order to maximize carbon sequestration rates. Nevertheless, the carbon released during management practices must not exceed the carbon stored in the vegetation in order to achieve positive net carbon sequestration [40]. Therefore, monitoring and management planning for maintaining vegetation post-construction is suggested as being vitally important, noting that net carbon sequestration must be positive [40], and will be included in step 4 of the conceptual framework [42].

The third and most noteworthy finding was that some respondents linked vegetation-based carbon sequestration to biodiversity (ecological) benefits. This indicates the importance of understanding these two aspects together to provide maximum synergies resulting in multiple co-benefits that are not limited to biodiversity conservation or carbon sequestration but include ecological and human health and well-being as well [36,73–75]. The literature highlights the co-benefits of considering these two aspects together but does not provide a method to integrate them into a building scale [13,15,76]. This reinforces the importance of this study and the purpose of this survey.

One of the findings from the habitat provisioning section is that biodiversity is site-dependent, and therefore measures must be taken to add vegetation to the building and its surroundings that are locally ecologically, climatically, and culturally appropriate. Although professionals sometimes add vegetation to the built environment as a habitat provisioning strategy for biodiversity conservation, human-induced ecological disturbances and spatial ecology considerations of most species are rarely considered [59]. Accordingly, landscape parameters, such as habitat availability, quality, connectivity, patch size, and barriers to biodiversity movement, and species-specific parameters, such as dispersal capacity, disturbance sensitivity, and local population size, must be considered [59]. The findings suggest a need for a methodological framework that accounts for enhancing biodiversity through employing buildings as a medium of habitat provisioning that not only connects smaller patches of habitats for different species to thrive but also regenerates the urban built environments from the landscape to the ecosystem level. This type of framework, which can be applied at a building scale for habitat provisioning, is missing in the literature.

It is observed that the response rate and ranking within each question (as extremely important or very important) are higher for the data gathering approaches and strategies subsections compared to the more technical questions related to the quantitative analysis of strategies (i.e., parameters, frameworks, and performance indicators). Therefore, these aspects will be further analyzed through the explanatory/qualitative research method in ongoing research. The exploratory phase (survey) results will be utilized for framing the types of questions that will be asked of the respondents in the explanatory/qualitative (semi-structured interviews) phase for a more detailed understanding. The great advantage of a mixed method approach in research is that the limitations of one method can be offset by the strengths of the other. When quantitative results need more explanation, qualitative data can reveal a more detailed understanding of them. In future research, the conceptual framework (indicated in Figure 2) will be further refined to include the recommendations suggested by respondents through this survey and information gathered through semi-structured interviews. This will help to determine how to implement design for carbon sequestration and habitat provisioning more accurately.

## 5. Conclusions

Regenerative design calls for progression beyond limiting negative environmental impacts and instead aims for positive, health-increasing socio-ecological benefits. Strategic design for carbon sequestration and habitat provisioning through building-integrated vegetation with an aim to deliver both carbon-positive and biodiversity-positive buildings has great potential to reduce some atmospheric carbon and conserve biodiversity. To encourage the widespread adoption of these strategies, this study identified and tested the acceptance by experts of a conceptual framework for implementing effective carbon sequestration and habitat provisioning into building design. This study contributes to the existing body of literature by focusing on the perspective of international professionals and researchers across multiple countries and, therefore, biomes and cultural contexts, rather than limiting results to a particular country. This research does acknowledge the inherent limitations of location and context-based bias that this approach has, which is an area of further investigation. The results from the descriptive statistical analyses show that the percentage of responses from environmental scientists and researchers was higher and more conclusive for each set of inquiries compared to built environment professionals. There were differences in opinions of both groups in relation to the strategies, frameworks, and co-benefits, as analyzed through the survey data. Therefore, engaging biologists and experts along with architects and landscape designers during the pre-design phase could be a practical approach to more effectively implementing the provision of ecosystem services into architecture.

Carbon sequestration and habitat provisioning are relatively new concepts to the building industry, and more awareness is needed, particularly in regard to practicing architects, landscape designers, and ecologists. The analyses demonstrated a need to engage all experts in designing, coordinating, monitoring, and managing such building projects by considering the benefits these ecosystem services provide, the barriers to implementing their strategies, and the potential solutions to overcome those barriers. A holistic design approach is required from inception to completion, including post-construction stages where such building projects evolve over time as vegetation grows and responds to seasonal cycles. Governments and local governing bodies can take the lead in instigating policies, plans, and programs that can enhance the acceptance of carbon sequestration and habitat provisioning strategies to combat climate change and biodiversity loss in the building environment design, construction, and management sectors. This study is a part of a larger research program and, as such, is just one step in identifying the co-benefits of the concurrent sequestering of carbon and the provision of habitats and how to implement this in the built environment design.

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**Data Availability Statement:** Data supporting reported results are available on request from the corresponding author.

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