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Review

A Review of Embodied Carbon in Landscape Architecture. Practice and Policy

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Abstract: This paper aims to discuss the importance of the climate crisis and embodied carbon in the landscape architecture sector. The study was carried out in a multiprofessional team with the collaboration of the Landscape Institute (LI) Chartered Body of Landscape Architecture, UK, and experts in the field. Using the expertise and knowledge of professionals as well as existing landscape examples and pioneering tools on carbon, this review paper focuses on the importance of low/net-zero carbon landscapes for our cities and regions and the ways in which these can contribute to the broader health and wellbeing of our communities. Examining the current situation on carbon methodologies and the latest knowledge on carbon calculations through a landscape lens, the paper explores why embodied carbon is important for open spaces/landscapes and the necessary policies to support a more efficient implementation of these concepts. The intensity of recent environmental challenges demands action. This review highlights the need for holistic approaches that integrate embodied carbon calculations on large-scale landscape design. Using the innovative example of the Pathfinder App, a carbon calculation tool, as well as other similar software, this paper argues that more steps are needed towards the calculation and adaptation of CO_2 emissions resulting from design, construction and materials in landscape schemes. The low availability of carbon calculation tools, specially developed for landscape schemes, is a major concern for the profession as it creates several issues with the sustainable development of the landscape projects as well as fragmented policies that exclude spatial and open spaces. Even though carbon calculation and embodied carbon are being calculated in buildings or materials, it is a relatively new area when it comes to land, the landscape and open and green space, and therefore, this study will present and discuss some of the pioneering carbon calculation tools focusing on landscape projects.

Keywords: embodied carbon; landscape design; climate crisis; policy; cities; whole-life carbon; landscape architecture; mitigation; place; space

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1. Introduction

The European Landscape Convention (ELC) supports the notion that landscape has a close interaction with nature, infrastructure and people [1], and therefore, these elements are all interrelated to the development of open areas. "Landscape" is a complex term to understand, as it represents many different levels of the spatial context as well as the social character of an area [2,3]. It is often perceived as a natural or ecosystem environment, the gift of nature; however, it can also be seen as the geographical area (a scientific approach) or an object of reproduction (artistic approach). Dealing with such a broad term in itself, it is often challenging to incorporate the concepts of carbon and climate change and how these affect our landscape and cities. The scale of climate change is becoming more widely recognised and termed the "climate crisis", so this becomes a particularly topical issue. As Zuoyan and Xiaojie [2] mention, environmental awareness in landscape design is becoming an inevitable part of social development, and this study agrees that landscape schemes cannot be designed without considering the environmental and climate challenges we face. Urban communities and their ability to deal with carbon metabolism can help in unveiling emission characteristics resulting from the development of low-carbon cities [4]. Going further, Selman states that "the landscape of carbon-neutrality will be strongly associated with careful choice of construction materials, and with subsequent renovation and maintenance" [5]; however, this study argues that this practice is still nascent, and more attention on landscape tools and policies will be needed to create wholly sustainable cities and regions.

Landscape has a primary role in the development of truly sustainable cities and regions, but for this to be achieved, the case of carbon, carbon metabolism and embodied carbon needs to be brought further into consideration. The objectives of the paper align with the role of embodied carbon in landscape architecture through the use of carbon calculation tools.

The methodology followed is based on a review and examination of current and past documentation of embodied carbon and carbon footprint as well as careful examination of available tools for landscape design schemes. Currently, there is limited or no use of standard carbon calculation tools for open spaces and landscape infrastructure projects. Even though open and green spaces can be very effective in terms of carbon absorption, there is a need for designers and professionals involved in the landscape process to be able to understand and calculate the carbon produced in landscape schemes (design, plants, soil, materials, transport, maintenance) if we are to mitigate emissions and maximise sequestration potential.

1.1. Cities, the Landscape and Carbon

Most people recognise climate crisis as one of the most significant challenges of our times, but there are still some who believe this to be a distant problem that affects only wildlife, secluded landscapes or remote locations, away from our cities and human settlements. The United Nations Intergovernmental Panel on Climate Change [6], though, states that an increase in global average air and ocean temperatures, warming of the climate system, global sea level rise and widespread melting of snow and ice are only a few of the effects of a changing climate [7] and the danger to human lives and biodiversity is apparent. Selman [5] mentions that "landscapes which have developed organically in relation to human needs are seen as having a 'functional fit', in which nature and culture share a parallel necessity—the result is that such landscapes possess an aesthetic because they 'look as they should'"; with the climatic issues across the globe intensifying, the impact on urban and rural areas is also becoming increasingly recognisable in an aesthetic/sensory context.

The severe changes appearing in coastlines, the numerous wildfires, the catastrophic flash flooding and the temperature rises in cities urge for alternative solutions to what has been done in the past, and as Ackerman et al. describe, "spatial designers are charged with the task of designing to mitigate these unknowns" [8]. This paper agrees that spatial designers should be at the forefront of a sustainable future, but it argues that this will require a step change from existing competencies and methods for landscape design. Landscape architecture and spatial design have a broad scope and operational field. Depending on the area and the challenge, a landscape scheme can represent urban and rural scales or even deal with national-scale projects. Ness and Xing [9] state that the built environment is much more than just buildings, including transport, water and energy in the form of infrastructure, but from a landscape perspective "infrastructure" is also included in the landscape scale, together with any natural and environmental characteristics of an area.

The severity of the recent environmental phenomena requires solutions that will not only address the local or urban scale but also represent a long-term approach for whole regions. The World Green Building Council [10] has highlighted that the construction industry and buildings are responsible for a significant amount of embodied carbon, while Ness and Xing [9] specify that the built environment relates to "40 per cent of material consumption, 40 per cent of waste and over 33 per cent of GHG emissions"; however, there is less clarity on similar data for landscape schemes and developments. What is required is for landscape architecture to be included in such data and be recognised as a critical part in the fight against climate change. Ackerman et al. [8] are right when they state that "landscape architects are well equipped to design for change and uncertainty, and to provide alternatives which may repair or deflect the damage caused by climate-change-related occurrences", but they cannot do it as effectively if landscape is not included in policy or is included without scientific measurements, such as carbon footprint and embodied carbon.

About 70% of the world's population will live in urban areas by 2050 [11], and it is also agreed that future climate change is an important factor impacting urban landscapes and sustainability [12]. Therefore, the need to respond to the imperative of carbon neutrality is urgent, despite the challenges that might occur for the landscapes and our communities. As Selman [5] explains, "the pursuit of sustainable development in an informed and democratic way can produce landscapes that people celebrate because they endorse their underlying narrative", and this is one of the goals for sustainable cities and regions.

Based on the IPCC's [6] data, it is still possible to restrict the increase in global temperature to 1.5 °C, but this would require "rapid and far-reaching transitions" in urban and rural environments, protection and restoration of ecosystems and significant changes in the way in which production and consumption systems operate. The C40 Cities Climate Leadership Group [13] admits that urban consumption is a key driver of global GHG emissions, and even though cities are creating action plans with the aim to reduce emissions, there is still the chance for such numbers to double by 2050 if not being actively chased. The question occurs on how landscape architecture can create new visions and approaches for urban and peri-urban landscapes and how a systemic and governance change can support the transition to a more sustainable future. The reduction of CO_2 emissions is strongly linked with reducing consumption [9], but as Welch and Southerton [14] warn, this requires "radical shifts" in the broader system of production and consumption. This is still not enough if a broader spatial vision is not put in place for the whole region, including environmental and awareness plans at a governance as well as a citizens' level of an area.

There are views that sustainable development will require a lot more than what is envisioned. Selman [5] notes that the notion of sustainable development with "cosy farming practices, mellow building styles and graceful local energy production is a contemporary myth", but almost a decade on, there are many different solutions either looking at environmentally friendly farming models [15] or net-zero buildings and energy schemes. This paper takes a more positive approach arguing that effective sustainable development is possible, but it requires the creation of aspirational spatial visions across regions and the swift of governance models to be able to support drastic changes in their territories. Landscape architects and designers are equipped to produce new approaches for our landscapes, but they need to consider how they become the "go-to" profession towards this significant challenge.

Manufacturers and the supply chain also require significant changes in order to mitigate the carbon generated in this sector. From the raw material production, supply, manufacturing, distribution and transportation to the use of materials and products and their waste recovery, there is a need for low-carbon strategies in the supply chain management [16]. The current market demand requires a large amount of products, resulting in "a large number of indirect emissions in the relevant sectors" [16], and this is an area that needs to be evaluated and considered when it comes to the source of materials for infrastructure development. There is evidence that "vegetation does the heavy lifting, but the manufacture and transport of other landscape elements share the burden" notes Klettke, who adds that there is continuous scrutiny on vendors to apply sustainability and metric methodologies [17].

1.2. Embodied Carbon Measurement Tools and International Policy Standards

The methodologies and metric tools on embodied carbon are continuously growing, with several governmental, scientific and professional institutions looking at ways to regulate emissions and work on the policy required. The "HM Treasury [18] has long recognised capital carbon, while the UK Green Building Council (UKGBC) has pioneered the adoption of embodied emissions within its framework for net zero low carbon buildings" [9]. Despite this recognition of embodied carbon as a major contributor to greenhouse gas emissions, there remains a huge gap in regulation and legislation of embodied carbon in construction. In the UK where 49% [19] of carbon emissions are attributed to buildings, there are only regulations for the operational management of buildings. Since the 2007 Sullivan report [20], various built environment groups have worked to control embodied carbon; the outcome of this work was the proposed Zero Carbon Building Regulations, but these were scrapped and with them a clear opportunity to regulate and reduce embodied carbon [19]. Recent calls for regulation in the UK have been led by Architects Climate Action Network, who are clamouring for an expansion of The Building Regulations to include requirements to assess, report and reduce embodied carbon within a new part: "Part Z: Embodied Carbon Emissions" [21]. However, these campaigns still focus on buildings and do not always apply to green infrastructure and the landscape. Lin confirms that "there are currently no international calculation guidelines for carbon footprint exclusive to landscape, [and therefore] it is reasonable to assume that any landscaping LCA should follow EN15978" [22]. It is also stated that the life cycle assessment (LCA) methodology originates from the ISO 14040 [23], and the first embodied carbon (EC) methodological studies appeared in ISO 21931 [24], but this does not address the lack of information in landscape architecture and spatial strategies, highlighting the need to develop guideline policies, as well as tools with a focus on landscape-generated embodied carbon. Social and political processes often shape how science is being perceived by decision makers [25], and therefore, it is important to pursue the creation of specific policy for the landscape and the built environment. Zuoyan and Xiaojie also emphasise that modern landscape architects have the challenging task of addressing environmental challenges and using design methods on conservation and environmental protection to achieve low-carbon designs [2]. This paper wishes to share information concerning this area and present examples that focus on climate-positive design for landscape architecture schemes. On a positive note, Ness and Xing [9] confirm that "tools are beginning to emerge that enable the calculation of both operational and embodied emissions such as the Precinct Carbon Assessment Tool".

The landscape and open spaces are very important for public health and our wellbeing, and the recent COVID19 pandemic has demonstrated how significant green infrastructure can be in our health and wellbeing as well as the fight against the climate crisis [26]. Calculating the emissions produced and absorbed by a landscape project is of great importance, as is having access to tools calculating embodied carbon in urban and rural locations. Kuittinen et al. [27] confirm that LCA tools on green infrastructure are scarce and lack specific standards, with the Environmental Product Declarations (EPDs) that are available for several construction products not being developed for plants, soils, mulches or other materials related to the landscape practice. The green infrastructure appears to fall behind compared to hard materials as well as the construction sector, since tools such as "LEED, BREEAM, DGNB, SITES, or Level(s), do not appear to offer sufficient information for quantifying the C uptake potential of plants, soils, and mulches". Kuittinen et al. [27] emphasise the impact of LEED on reducing CO_2 in the construction of buildings and materials without giving any information on how (and if) this tool addresses the landscape overall or even specific open space elements.

The lack of metric tools is not only a data gap, but it reveals a greater challenge of the landscape sector being overlooked and highlights the danger of focusing only on technological solutions without seeing the bigger picture or understanding that a holistic spatial approach is required in order to achieve a smooth transition to a net-zero carbon future. Responding to this challenge, some individual tools looking at landscape elements have started to emerge, but there is no coherent approach for the entire landscape architecture profession. The i-Tree software is a tool exploring carbon in trees. According to the USDA Forest Service et al. [28], "the i-Tree software is developed for estimating the quantity and economic value of some ecosystem services provided by urban trees, including C storage and sequestration, air pollutant binding, storm water attenuation, production of volatile organic compounds (VOC), and effects on building energy use"; however, this is currently only applicable in North America. From a landscape profession perspective, a promising tool is the Pathfinder, "a climate-positive app for landscape architecture that helps designers identify and sort products with low-carbon characteristics, which should drive manufacturers to eventually establish Environmental Product Declarations (EPDs) according to ISO standards" [17]. Due to its use by practitioners and the fact that this tool can calculate embodied and operational carbon emissions and sequestration for site design projects, the Pathfinder has been selected as a key example of this paper followed by other tools integrating landscape characteristics.

2. Materials and Methods

The research supporting this review paper explores the meaning of embodied carbon and carbon policy in spatial strategies and landscape practice. This wide scope is necessary to analyse the importance of carbon calculation in landscape-led projects and strategic designs and the reasons why tools for such calculations need to be developed and specialised for this profession.

The research question formulated based on the screened literature on embodied carbon for landscape was as follows:

Q: What is the role of embodied carbon in landscape architecture through the use of carbon calculation tools?

The study was carried out in a multiprofessional team that possesses both scientific and practical experience in sustainability assessment, landscape architecture, climate policies and regulations. After an extended examination on the availability of carbon tools specially developed for landscape projects and using the expertise of landscape professionals, the most appropriate ones have been selected. It is important to clarify that this review tackles a gap (landscape-embodied carbon) that has been overlooked, creating challenges even in the identification of relevant tools. Extended research on carbon calculation tools for landscape schemes has been carried out to demonstrate the availability of such methods as well as their significance to the design of our future cities. Four carbon calculation tools are identified and presented, the "Climate Positive Design Pathfinder", the i-Tree, PCA and EC3 tools. The paper provides insights into the tools and their scope and use in landscape architecture and discusses their importance as well as suitability in landscape projects.

2.1. Literature Search

A literature search has evidenced the lack of carbon calculation software targeting landscape architecture. An additional electronic search of relevant academic literature was conducted using the keywords "embodied carbon" "landscape design" "landscape architecture" and/or "whole life carbon." This search was conducted using the ScienceDirect search engine [29]. The use of ScienceDirect database is rationalised by its vast inclusion of peer-reviewed journals and conference proceedings across various areas within the landscape architecture field. ScienceDirect also allows looking for document titles, abstracts and keywords with relevance to particular areas of research.

The ScienceDirect queries used to conduct the search are as follows:

- TITLE-ABS-KEY (embodied carbon) AND TITLE-ABS-KEY (landscape design) AND TITLE-ABS-KEY (landscape architecture) AND TITLE-ABS-KEY (whole life carbon) = 5 results;
- TITLE-ABS-KEY (embodied carbon) AND TITLE-ABS-KEY (whole life carbon) = 1203 results;
- TITLE-ABS-KEY (embodied carbon) = 31,289 results.

The above review methodology was used to justify the gap tackled by this review and the significance of the topic for landscape architecture. The literature search has been followed by extended research, consultation with professionals and scanning of available tools suitable for landscape designs. The four tools identified are the most relevant, according to the research team, in relation to the landscape and green infrastructure. Initial analysis for each tool has been conducted evaluating their scope, scale, suitability for strategic schemes and the elements they are able to calculate (e.g., embodied carbon, environmental characteristics, landscape or buildings).

2.2. Policy Contextual Review

The paper also reviews the policy context within the UK by conducting a search of relevant policy documents, government reports, white papers and parliamentary papers. A similar search was also conducted of documents published by key industry, trade or professional organizations. Government documents were searched on the UK government database [30]. Searching industry documents required the use of a stakeholder map developed by the Landscape Institute which contained key UK-based non-governmental organisations and industry, trade and professional bodies. Using this list, each organisation's website was searched for relevant embodied carbon documents of both policy and practice.

Literature has also revealed that the development of standards and calculation tools is interrelated with policy and legislation, and therefore, this study has examined the current policy landscape with the aim to highlight its relevance in the development of carbon tools. An additional investigation has been conducted in policy documents that focus on embodied carbon. Examinations and assessments on policy are made, and several suggestions are given in order to improve the carbon calculation of landscape projects. As policy and legislation differ in different countries, the decision has been made to present findings from the UK; however, the goal to emphasise their importance at an international level remains, and data are given wherever possible.

2.3. Case Study Review

The Landscape Institute (LI) hosts a large array of landscape practice case studies on its Case Studies Directory, with 498 examples of practice, design and management of landscapes from across the world. A search with the terms embodied carbon within the directory yielded nine case studies. A further review of these nine case studies showed that three of the projects focused on creating carbon sinks and using sequestration, three projects were spatial strategies to reduce carbon through the integration of on-site renewable energy and three other case studies implemented design practice to minimise carbon both operationally and embodied. However, one theme linked all these case studies: the embodied carbon footprint of their construction had not been examined at least in the evidence provided by the case studies. Therefore, this study recognises the lack of testing between the carbon calculation tools and landscape design schemes. An ongoing example of a UK study from Gillespies landscape practice has been employed to test and evaluate the benefits of the carbon calculation tool Pathfinder and share insights on how this can be put into practice in a UK and European context. The Gillespies approach serves as a practical example in this research, testing one of the tools (Pathfinder). The authors have collaborated with the Gillespies team to analyse and understand how the Pathfinder tool works in landscape design and what the benefits in relation to carbon calculation are. However, this is still an ongoing process, and only preliminary results are discussed in this paper.

Research methods consisted of examining current and past documentation of embodied carbon and carbon footprint and carefully examining available tools for spatially oriented schemes. This first stage has allowed the identification of the most developed carbon calculation tools and their further exploration in relation to landscape projects. An initial evaluation of the tools and specific requirements for the landscape profession are presented in this review. The tools were selected for analysis using several criteria. One of the main criteria for the selection of the software/tools was their accessibility; they needed to be open source and user friendly so that they could be used by landscape practitioners with a broad spectrum of technical expertise and resources. Secondly, many of the tools on the market are primarily aimed at calculating the embodied carbon of buildings rather than landscape projects; tools that were incompatible with potential use in landscape design projects were omitted.

2.4. Tools

As mentioned earlier in the paper, there are limited tools examining carbon from a spatial-led approach; therefore, the selection of the apps and software below is based on their ability to accommodate (or partly accommodate) embodied carbon calculations in landscape projects and green infrastructure. Four tools were explored, with one tool being applied in a UK context by a landscape practice (Pathfinder) and one other tool being tested by Forest Research UK (i-Tree). The tools selected by this paper as case studies were chosen based on their landscape-led approach or, in some cases, the elements of their functional analysis, such as carbon sequestration and pollution. Most of these tools have been developed in a Northern American context, however, efforts have been made to assess the tools' functionality in a UK and European context whenever possible.

The Pathfinder tool was part of the Climate Positive Design approach [31] launched by Pamela Conrad, Principal Landscape Architect at CMG Landscape Architecture, in 2019 focusing on increasing social and ecological wellbeing through design. It has been developed to reduce carbon emissions from the spaces outside of buildings and support the measurement and sequestration of carbon in the built environment. As Conrad mentioned in communication with the Landscape Institute (LI) team, as well as presentations of the Pathfinder tool, the carbon emissions related to the landscape profession are operational, related to landscape maintenance, materials, plants and other natural elements related to design. The Pathfinder tool also provides education and awareness about what climate-positive design is and why it is important in supporting the movement towards resilient cities and regions.

i-Tree tools are a collection of software suites created by the USDA Forest Service. i-Tree consists of six core tools aiming to provide support in the climate crisis. The flagship tools of the software are i-Tree MyTree, i-Tree Landscape, i-Tree Design, i-Tree Canopy, i-Tree Eco and i-Tree Hydro. i-Tree Landscape and i-Tree Design allow the user to explore land cover and tree canopy and see how trees improve the landscape and natural characteristics of a selected area, and they also allow for calculations of energy benefits from trees next to buildings [28]. i-tree Eco is the tool selected for this paper as it quantifies key metrics on the composition of urban trees. These data include species composition, condition (health), canopy cover and the replacement cost of trees. This information is vital to understand the treescape of landscape schemes and identify future risks.

The Precinct Carbon Assessment (PCA) tool provides end-users with the capability to assess different low-carbon development options The PCA tool can be used as an assessment tool at the final phase of a development project or as a planning tool applied at an early stage of a project. The tools measures embodied carbon, operational carbon and "Travelling Carbon Emissions" (transport use of populations in the model).

The Embodied Carbon in Construction Calculator (EC3) tool allows benchmarking, assessment and reductions in embodied carbon, focused on the upfront supply chain emissions of construction materials. The tool uses building material data from verified Environmental Product Declarations (EPDs). With these data, the tool can be used in the design and procurement phases of a development project.

3. Results

The main tool of this paper is Climate Positive Design's Pathfinder tool, as it is the most developed software to date allowing for carbon calculation in spatial contexts. A preliminary trial of this tool has been conducted by the UK-based landscape practice

Gillespies, and some initial results have started to emerge. In addition, the i-Tree, APC and EC3 software are presented here with the aim to identify other promising tools for carbon calculation in the landscape context (Table 1).

Table 1. Selected tools and key elements.

Tools	Landscape Focus	Use/Applied to	Carbon Relevance
Pathfinder	Very significant	Landscapes/Green Spaces	Calculates project sequestration
i-Tree	Significant	Green Infrastructure (trees)	Calculates impact of trees
PCA	Less significant	Buildings	Calculates environmental elements of buildings
EC3	Less significant	Planning/Buildings	Calculates carbon related to materials and construction

3.1. Climate Positive Design's Pathfinder Tool

Pathfinder is a free-to-use web-based app that allows practitioners to measure the carbon footprint of their projects and actively encourages users to achieve carbon-positive projects in recommended timeframes. Currently, it is North America-centric, but tests are being conducted for it to be used in projects around the world. The data that are built into the database come from the Athena Impact Estimator (where the embodied values come from) [31] and the Forest Service for sequestration data, verified by external environmental consultants. Essentially, the app calculates how much carbon is released from material use, construction, maintenance and transport and, conversely, how much carbon is sequestered by planting and green infrastructure. Pathfinder records the embodied carbon of materials used in the project (comprising the extraction, manufacture, transportation, installation, use/maintenance and replacement of construction materials), emissions generated from demolition prior to construction and emissions from the installation of planting and soils. The user can select their area and provide quantities for their projects (materials, plants, maintenance), and the app provides instant scorecards (Figure 1) and feedback on carbon emissions. This information can be extracted and used in broader lifecycle assessments of the area. There are also several data assumptions that the tool makes, including emissions for transport, construction and end-of-life process are assumed as 30% of the emissions from production, so it should be recognised that, depending on project location and material sources, this will, in reality, vary project to project. These calculations allow the designers to be able to see a projection of how much carbon is emitted and sequestered by their designs and be able to adjust and make calculations to reduce these numbers by adding more trees, selecting local material and re-evaluating their designs. It also allows calculations on how long it will take to offset the emitted carbon, revealing the date when a project becomes climate-positive. According to Pamela Conrad, there were examples where simple changes in design could decrease the carbon sequestration of a project from 200 to 20 years, meaning that the specific landscape scheme could offset its carbon in 20 years following the changes in the design.

In the United States, where the tool has greater uptake and is better tailored, several landscape designs have used the app to measure and reduce embodied carbon. One such example is DePave Park Vision Plan [32], a design idea by CMG Landscape Architecture. The concept idea is to turn a paved 14-acre western edge of a seaplane lagoon into an ecologically rich wetlands park. CMG Landscape Architecture used the Pathfinder app throughout the design process to calculate and manage the embodied carbon of the project. Careful reuse of existing materials and large-scale restoration of wetlands have led to a minimisation of carbon emissions and a maximisation of carbon sequestration. According to the calculations completed by CMG, the new design will offset its carbon footprint in 4 years and mitigate the carbon footprint of its original construction in less than 25 years, as opposed to the original 220 years the current site required to offset its carbon impact.

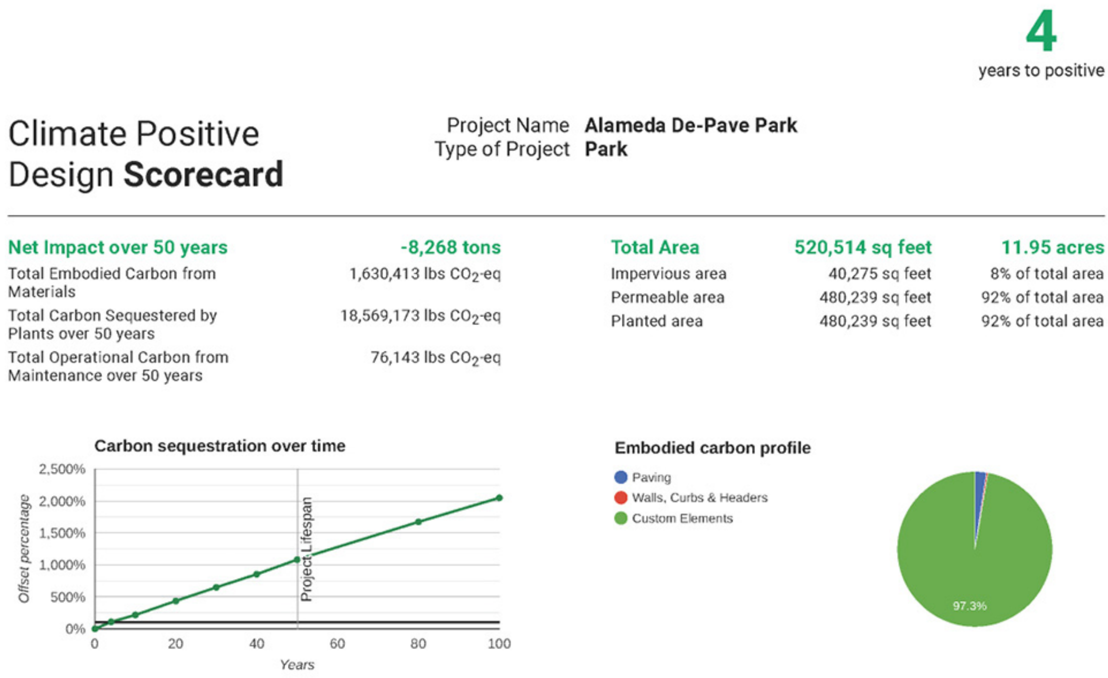

Figure 1. Example of a scorecard with the use of the Pathfinder tool, demonstrating the embodied and sequestered carbon over 50 years. Source: CMG Architects.

A key barrier for wider adoption however is the lack of data for a UK or non-North American context. In order to make the tool more specific and accurate for a UK or European context, there is an option to create custom elements that have data and characteristics relevant to European countries. The common challenge though is that these datasets are provided by suppliers, and at present there are few firms providing such information, resulting in issues with the tool's use. Some pioneering manufacturers and contractors with an environmental agenda have started to develop the data required [33], but this is still in an experimental phase. Vestre, a Norwegian furniture maker, has plans to integrate their products into the Pathfinder tool so that they can be selected from a pre-programmed set of furniture. Marshalls, a UK-based paving manufacturer, is currently providing the carbon footprint of their natural stone paving on datasheets to support carbon calculation when designing or implementing infrastructure schemes. This will allow the accurate calculation of carbon; for example, the carbon footprint of Yorkstone quarried in the UK will be compared to a granite quarried in China and a decision for carbon offset, transport emissions and costs will be made. Nevertheless, there is still a long way to go until this information can be added to the Pathfinder or similar software. Barcham, a UK-based group of tree specialists, is now providing the sequestration rates for all its trees, a very significant step towards carbon calculation in relation to trees and natural elements. Again, this is a custom element that can be added to Pathfinder for a specific tree species or other similar software.

Gillespies (a landscape architecture firm) is trialling the use of the tool in a project in the UK [33]. In 2021, Gillespies began using Pathfinder in its landscape projects; a recent example is the firm's shortlisted competition entry for a redesign of Leeds City Square. Using the Pathfinder app, the team was able to calculate the embodied carbon of new materials (furniture, paving and lighting), demolished materials and renewable energy infrastructure. According to the team at Gillespies (interview with LI team, 2021), there remained gaps in data for the use of imported topsoils, and several assumptions had to be made for various materials, including paving and concrete. The data for carbon sequestration potential were also collected; these were primarily in the form of estimates of on-site planting, approximating deciduous planting as the main carbon sink. The team at Gillespies used Pathfinder's pre-set data where they were available but also worked with UK-based suppliers to provide some parameters; for example, tree-planting data were provided by Barcham and some of the paving data were provided by Marshalls. The shortlisted entry did not win the final selection, but the concept work provided a valuable insight into how the Pathfinder app could be used in the UK context.

3.2. Alternative Carbon Calculation Tools (i-Tree, PCA, EC3)

The i-Tree tool was selected for study due to its capability to capture and visualise the impact of trees, a significant part of green infrastructure and landscape projects. An additional reason for its selection is that one of the i-Tree's sub-tools, i-Tree Eco, has been tested in the UK. i-Tree is a software that is able to assess structural and physical characteristics of trees and forests and calculate carbon sequestration [34]. Even though it does not cover a broader landscape carbon calculation as Pathfinder does, it offers significant calculations in several important areas. However, this is still focused on trees and does not provide a broader carbon sequestration calculation of a landscape project that includes other natural features such as plants, grass, mulch, water and hard materials. i-Tree Eco is one of the sub-tools applicable outside North America, and it is being tested in the UK in collaboration with Forest Research with the aim to deliver i-Tree UK [35]. i-Tree Eco is able to analyse carbon sequestration and storage, bio-emissions, interception, run-off, transpiration, UV, building energy effects, pollution removal and health impacts based on data from individual trees and forests in the area [34]. This is a significant step towards the carbon calculation of landscape schemes, although, at the moment, it is based on existing forests and canopies and does not include the design element the landscape profession requires for a project proposal. The interest from several stakeholders, such as government agencies, consultants, academia, NGOs and the public, demonstrates the need to understand and be able to calculate carbon emissions when we design and deliver sustainable schemes in our cities.

Other tools such as the Precinct Carbon Assessment (PCA) and the EC3 tool have started to emerge. The same issue remains when it comes to landscape projects and open spaces. Although the tools accommodate buildings and cities, there is no coherent approach to how natural elements and green infrastructure should be calculated. For example, the PCA tool developed by the Department of Industry, Innovation and Science of Australia mentions the importance of neighbourhoods, cities and social characteristics in the urban system, but there is no information in the software that allows for the embodied carbon of a wider landscape area to be fully calculated. Importantly, the PCA tool consists of functions that analyse local climate, land use profiles, water and waste-related energy, embodied and operational carbon and carbon offsetting [36]; however, these are mostly related to building and infrastructure types. Some of the parameters calculated are important from a nature perspective (e.g., water, energy, land morphology), but the current model does not allow for calculations of a holistic spatial area, nor does it allow consideration of how embodied carbon might affect the overall character of a landscape and therefore its impact on the city or region. As suggested by the relevant report, "PCA can be used as an assessment tool at the final phase of a development project or as a planning tool applied at an early stage of a project" [36]. What this paper acknowledges though is that despite the several parameters in the PCA tool, there is still not a clear approach when it comes to landscape schemes and natural elements. It is mentioned that the tool can be applied to "greenfields", "greyfields" and "brownfields", but the focus remains on residential and mixed-use areas and predominantly on buildings.

The EC3 tool is a good example of an embodied carbon calculator; however, it focuses on buildings, construction materials and supply chain emissions. The tool had input from approximately 50 industry partners, with the support from the Carbon Leadership Forum [37], and it works in relation to Environmental Product Declarations (EPDs) and BIM. The tool appears promising for the construction sector, as it allows policymakers, architects and contractors to set embodied carbon limits and assess supply chain emissions; it does not deal with open spaces or green infrastructure but instead focuses on materials and construction. This paper acknowledges that the focus of the EC3 has been embodied carbon in relation to buildings; however, it would be very interesting to see an upgrade including green infrastructure and natural elements. Especially since the tool is compatible with BIM, it would be a great addition and of good use to designers to be able to calculate the landscape carbon footprint in landscape-led schemes.

4. Future Policy and Regulation Frameworks

This paper has examined the embodied carbon policy and regulatory frameworks in the UK and proposes recommendations to encourage the broader use of whole-life carbon approaches in the landscape design sector. In 2019, the UK was the first major world economy to pass a net-zero emissions target into law (draft Climate Change Act 2008 (2050 Target Agreement) Order 2019) [38]. This target, which was recommended by the Committee on Climate Change, requires the UK to bring all greenhouse gas emissions to net zero by 2050 [39]. The built environment is a major contributor to UK emissions. According to the Climate Change Committee, the independent body which advises the government on emissions targets, buildings account for 34% of total UK greenhouse gas emissions [19].

Broadly speaking, UK regulation has focused on in-use and operational carbon of buildings as these make up the majority of most buildings' emissions. Part L of the Building Regulations strengthened energy efficiency requirements, and the construction industry has sought to improve fabric performance, heating systems and lighting. The regulations have brought about reduced operational carbon, and the government will seek to build momentum by updating Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations with more robust measures. Regulation rather than voluntary initiatives has brought about positive industry change; action on embodied carbon remains predominantly unregulated and is lagging behind the operational use reductions. Therefore, in a well-designed low-energy building, embodied carbon emissions are over half of the total carbon emitted across the building's lifetime [40]. Across Europe, embodied carbon emissions have been targeted; regulations are to take effect in France, Finland, Denmark and Sweden before 2030, with the Netherlands already regulating since 2018. In the United States, California, Minnesota and Oregon already have state-level carbon requirements, and the federal government is looking at draft legislation [40].

Analysing recent reports from UK governmental bodies, it is clear that policy change is being explored and considered. The government's own climate advisers, the Committee on Climate Change, commissioned a report by AECOM in 2019 [41] exploring "options for bringing embodied carbon into the building standards framework". The report asserted that "mandatory targets are likely to be more effective" than the kinds of voluntary codes that currently exist in the UK.

The clamour for reform is growing amongst stakeholders, and there are many industry groups now calling for change. Two such groups are Architects Climate Action Network (ACAN) and Part Z. ACAN has identified several key areas for policy changes within the scope of Building Regulations Planning Policy use of British Standards Public Procurement and Tax Rules. Part Z is a partnership of sustainability specialists, which includes authors from the Royal Institute of British Architects and the Institution of Structural Engineers. The Part Z collective is calling for an additional section to be added to the UK's Building Regulations, known as Part Z. Part Z regulations will be divided into two sections. The first, Z1 Carbon Assessment, requires that whole-life carbon emissions shall be assessed and reported for the building and any other parts of the project where Building Regulations apply. The second, Z2 Carbon Intensity, ensures that reasonable provision shall be made for the minimisation of carbon emissions [21]. Part Z1 is intended to normalise the use of whole-life carbon assessments within the building design process, enabling design teams to identify ways in which to reduce the whole-life carbon impact of the building. Assessment data will also be used to determine national targets for embodied carbon that will be used for Part Z2. Part Z2 is intended to discourage excessive and unnecessary use of resources within the built environment by setting a reasonable standard of efficiency for the upfront embodied carbon intensity of the building. These proposed regulations, whilst not enacted, signal a potential shift towards greater regulation to mirror what other countries are already decreeing. Within this regulatory movement, it is vital that landscapes and open spaces are also considered to deliver against climate change commitments. This regulatory and policy change could take several forms. Currently, Building Regulations in the United Kingdom perhaps unsurprisingly focus solely on buildings, but buildings themselves are just one part of the built environment, and parks, open spaces and places all play a key role. There is a broader argument beyond the scope of this paper about the inclusion of open spaces, parks and green spaces or essentially “the spaces between buildings” to be included in a framework of Building Regulations. Whilst there are some tangential regulations in the “Right to Light” governmental report [42], most open spaces remain excluded from this form of regulation. Purely as a mechanism for stimulating the measurement, reduction and management of embodied carbon, this form of regulation could potentially have similar effects to the proposed Part Z regulations. Regulation could also arrive from the “client-side”. Some local authorities in the UK have already included mandatory cradle-to-gate embodied carbon assessments as part of their planning process (e.g., Brighton and Hove City Council). The new draft London Plan [43] introduces a requirement for all new referable developments to calculate and reduce whole-life-cycle carbon (WLC), i.e., both their operational and embodied emissions.

Regardless of an optimal regulatory framework, the landscape profession still needs the data and supply-side EPDs to succeed. Indeed, in 2014, the Embodied Carbon Industry Task Force recommended that the WRAP Buildings Database be maintained and updated to enable measuring and reducing embodied carbon. This database, now managed by the Royal Institution of Chartered Surveyors [44] focuses predominantly on building materials. During the Gillespies trials and within the Landscape Institute’s Embodied Carbon Advisory Groups feedback (workshop information used for this study), it is apparent that there is no central database for materials commonly used in landscape designs. Having a database is a vital building block to enable landscape practitioners to calculate embodied carbon measurements, and whilst some suppliers have begun furnishing various databases, a lack of centralisation could reduce uptake within the industry. Therefore, it is vital that landscape practitioners, suppliers and professional bodies contribute towards a centralised database; updating and including data in an existing database would help reduce duplication and oversaturation.

5. Discussion

The importance of landscape design and embodied carbon for our cities’ resilience, health and community wellbeing has been explored throughout this paper. The tools selected as case studies and examined in relation to their attention to landscape-led approaches or natural elements of the built environment have provided significant information towards carbon calculation. However, this research reveals there are still significant data gaps when it comes to carbon calculation in the landscape context.

Focusing on carbon footprint, embodied carbon and carbon sequestration, all examined tools try to provide accurate calculations for embodied carbon or carbon footprint; however, it is apparent that this is not possible without multidisciplinary teams and the collaboration of the manufacturers, designers and policymakers. Most tools focus on hard materials and the built environment [20] without providing accurate data when it comes to wide landscape areas, trees and natural elements used in landscape schemes. However, the Pathfinder and i-Tree tools recognise the importance of green space, water, morphology and land use in the fight against a changing climate. In particular, Pathfinder is a landscape-led (possibly the only one developed by landscape architects and targeting professionals in this field thus far) software that not only deals with carbon calculation but also touches upon the importance of awareness as well as a climate-positive design. Instead of being a merely numerical tool, Pathfinder focuses on future predictions of carbon sequestration, allowing the designers to understand, consult and finally re-assess their designs based on a more environmentally friendly approach. As Klettke explains, this can eventually lead to the creation of further environmental standards with a focus on the landscape [17], and this study agrees that policy needs to be in place to support the development of landscape-focused carbon calculation tools. The exploration and assessment of the selected tools have revealed that carbon has a key role in the design and development of landscape schemes since carbon emissions relate to several areas from the design to operation, manufacture, materials and maintenance of the project. Even though the landscape profession can provide solutions and environmentally oriented designs, the lack of data and awareness results in the opposite outcome. This review aims to highlight the value of the landscape in the journey towards climate resilience and the significance of available methodologies/tools that allow landscape architects to be fully aware of the embodied and sequestrated carbon in their designs. As Ackerman states, landscape designers need to be equipped to resolve unknown challenges [8], and the ability to be able to predict the carbon sequestration of spatial schemes is a great tool to have.

The approach adopted by most of the tools at the moment is to numerically calculate the carbon sequestration or emitted carbon without considering the overall aesthetic or social value in the area. A carbon calculation tool focusing on the landscape will allow for the measurement of carbon while creating opportunities for more sustainable and climate-positive designs. For such an approach, a dedicated tool of carbon emissions/sequestration for spatial strategies is required, but there is also a need for policies that promote uptake.

This review has revealed large gaps in current regulations and missed opportunities in proposed reforms. The first area highlighted is the lack of landscape representation in the UK Building Regulations and their proposed enhancements. Omitting open spaces, green spaces and public realm places creates a fragmented regulatory framework for the built environment. Ensuring that landscape schemes are part of any proposed embodied carbon regulation could encourage better measurement, reduction and capture of embodied carbon by landscape professionals.

6. Conclusions

As the climate-related challenges become more frequent and intense, this review seeks to demonstrate the need for a broader holistic approach to landscape design and embodied carbon. The lack of a coherent strategy for the calculation of emitted carbon and the long-term benefits of carbon sequestration in spatial schemes is apparent. Identifying landscape-led tools and their level of intensity in carbon calculation is rather interesting as it provides evidence for the lack of such data in the landscape field. Landscape and open spaces are often seen as the aftermath of a new design, and therefore, most of the available carbon calculation tools focus on buildings and hard materials. This study has underpinned the process of available tools and started collaborations with UK practices in order to test and evaluate the available software; however, the lack of data is proving rather significant, making this a long and challenging process. The awareness of environmental impact and climate-positive design is very significant if we are to address the climate challenges we face; however, landscape architecture must take a front role in the way we understand, design and live in our cities. This review study recommends the further development of landscape-led tools that calculate emitted and sequestered carbon in spatial schemes, along with the key role manufacturers play in this. Successful calculation of carbon footprint and offset in strategic schemes will not only address the technical challenge of meeting carbon regulations but also boost the value of the landscape and create greener, healthier and community-friendly environments. The tools are not presented in this study as best practices and technological solutions for a Net Zero era, but as the mediums to support the landscape profession in its role towards climate resilience and sustainability.

Policy and the way it affects the establishment of landscape architecture in the "carbon field" have been assessed. It is significant to state that policy and regulations are crucial tools for moving forward. Especially when it comes to intangible elements, such as sense of place, health and wellbeing, they can provide the necessary thrust for an environmentally led way of living. It is apparent that policy focuses mostly on buildings, and therefore, this paper has the following recommendations:

- Incorporation of landscape materials in a national database;
- Inclusion of landscapes and open and green spaces in embodied carbon building regulations;
- Increased training, guidance and professional development to enable landscape practitioners to use whole-life carbon approaches.

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