AN URBAN FEASIBILITY STUDY INTO BALANCING UPFRONT EMBODIED CARBON EMISSIONS THROUGH INTEGRATED GREEN AREAS AS CARBON OFFSETS

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ABSTRACT

Upfront embodied carbon calculations account for concentrated carbon dioxide emissions into the atmosphere in the production of building materials and construction of buildings. To lower these emissions within a single building site to zero carbon is often extraordinarily difficult and offsets or sequestration are often required. This paper presents an exploration into integrating carbon sequestering green measures into new building design. The exploration looks at five different scales in a case study city, Christchurch, New Zealand. The objective was to test the definition of 'site' in a net zero carbon future. It discusses the scientific and social benefit of different strategies at different scales. The paper found that the city and region scale have the best potential for balancing the embodied carbon emissions from new buildings. The scale also has the potential to apply biophilic design logic to the application of strategies to improve the quality of the urban environment.

Keywords: embodied carbon, offsets, carbon sequestration, urban, biophilic

1 INTRODUCTION

Limiting global warming has become a high priority agenda item for many countries. As population growth puts pressure on cities, the demand for new buildings increases. Without systems for accounting for carbon offsets within the local building design processes new buildings will continue to seek to 'purchase' large quantities of a diminishing resource: carbon offsets for the carbon impact of their consumption of the earth's natural resources. This paper presents a modelling scenario as an exploration into balancing the embodied carbon emissions from building through the integration into the design processes of carbon sequestrating landscapes at different scales. The World Green Building Council (2019) estimate that buildings contribute

39% to the world's total carbon emissions, with approximately 11% being contributed from upfront embodied carbon. As the world's population grows, so too does the demand for new building stock. They suggest that this demand will consume an immense quantity of natural resources and will contribute to the doubling of global consumption of raw materials by the middle of the century. Buildings consume a large quantity of raw materials. This can be recorded as the amount of carbon added to the atmosphere during mining, manufacture, and construction – typically labelled 'embodied carbon'. Carbon emissions occur throughout the life cycle, but they are concentrated in the product and construction stages, commonly referred to as upfront emissions. Accounting for these emissions is critical as they are built in through the design and the materials selected, once installed they cannot be changed, and they are a significant fraction of the total carbon emissions over a building's lifetime.

1.1 Targeting Net Zero Embodied Carbon

In many countries embodied carbon is largely unregulated. However, there are efforts by Green Building Councils and professional organization institutes to outline a pathway to reduce embodied carbon overtime (NZGBC 2018; Adams, Burrows, and Richardson 2019; LETI 2020; RIBA 2019a; 2019b). The advice across all is to urgently start making reductions from reuse and recycling of carbon intensive building materials (Lupíšek et al. 2015), material minimization (Giesekam et al. 2014), optimal building design (Hawkins et al. 2020; Gan, Cheng, and Lo 2019), efficient construction processes (Teng and Pan 2019), adaptive reuse of buildings (Pelling 2010), and reducing the impact of transport of materials (Kumari et al. 2020). However, all of these strategies will only reduce the total embodied carbon emissions but will not achieve a net-zero carbon result.

The use of bio-based materials such as timber produces a promising approach for some buildings to claim the biogenic storage benefit. However, it is not possible for every building to be built from timber, therefore it is likely that many buildings will need to invest in offsets to achieve a net zero result. Carbon offsets are governed internationally by the Kyoto Protocol (United Nations 1997). There are many different types of offsets available but for the purpose of this paper, offsets through carbon sequestration of terrestrial systems will be explored as a strategy.

1.2 Lack of Motivation to Mitigate Climate Change

Whilst strategies to reduce embodied carbon emissions have been widely discussed in the literature (Kumari et al. 2020; Lupíšek et al. 2015; Cabeza et al. 2013), the building and construction industry faces a common problem that delays action in adopting strategies. This problem is connected to the perceived negative message from measuring the damaging impact a building is having on its environment. Dramatic and catastrophic messages about climate change have been eye catching in the media for decades but have ultimately been argued to be counterproductive when engaging people to act (O'Neill and Nicholson-Cole 2009). One study found that people who were emotionally passionate about taking action to mitigate climate change were motivated by "objects of care" such as protecting the future of their family, community or local environment (Wang et al. 2018). Another study argued that a scientific understanding and representation of the problem is only one perspective and that a meaningful response to action is linked to understanding the dynamic social context of people (Finucane 2009). Whilst science has the benefit of precisely recording and documenting changes over time, inspiring change over time requires the recognition of underlining qualitative conditions that motivate people to take action.

1.3 Achieving Net-Zero Embodied Carbon Through Carbon Offsets

If it is assumed that most buildings will require some form of carbon offset to balance the upfront embodied carbon emissions, and that, on the basis of Wang et al's (2018) paper, people will be more inspired to take action if there is a positive emotional connection to the solution, it is important that the process of offsetting carbon doesn't also trigger a negative association. In many countries, under either a carbon taxing structure or emissions trading scheme, carbon is given a financial value which often correlates to the cost to offset a tone of carbon. Adding an additional cost to the construction of buildings to achieve a net-zero outcome has the potential to inflate the already very negative reality of climate change. However, Robinson (2016) demonstrates in an Australian study that developing social responsibility over the environment leads to growth in the perceived relationship between social and ecological benefits. Along with another study from Australia (Renwick et al. 2014) alignment of local carbon offsetting projects with an indigenous world view not only reduced overall carbon impact but also empowered communities.

Whilst evidence for the social and cultural benefits of local carbon offsetting projects is still emerging, there is widely accepted evidence for the benefit of strengthening the relationship between architecture and the natural environment through a biophilic approach (Almusaed and Almssad 2006; Soderlund and Newman 2015). A biophilic approach to enhance the quality of the built environment seeks to connect its inhabitants more closely to the environment. Xue et al (2019) queried participants in a biophilia workshop suggesting that strategies for biophilic design can be implemented at the building or city scale. They found that research about the immediate effect of Biophilia Design on human body is well accepted and provides strong evidence for stakeholders and decision makers; however, those surveyed noted that the intermediate effect or long term effect of Biophilia through urban infrastructure and management is less well researched. Of the many biophilic strategies, those that increase the green space within and around building and cities have the potential to provide an additional benefit of sequestering carbon. These include: increase green space coverage ratio (Barton and Pretty 2010), enhance native species ratio (Oldfield et al. 2015), natural landscape promotion with minimal management (Hwang and Yue 2015), and green walls (Beatley 2012; 2016).

1.4 Urban Carbon Sinks and Management

Guo et al. (2017) examine the balance of carbon cycles of urban environments. They identify carbon sinks as fundamental in achieving low carbon development and improving local sustainability. However, from a carbon cycle perspective, they also point out that there is still no agreed integrated methodology to evaluate sustainability within a local urbanization process. For example, Zhang et al. (2012) used a dynamic land ecosystem model to measure the impact of carbon sinks located within urban environments that were previously deemed too small to consider. Strong et al. (2011) used a multiple-box model to combine meteorological, anthropogenic, and biological processes to develop an understanding of diel carbon cycles over four seasons. Further, in an effort to explore exchange of carbon between the atmosphere and terrestrial biosphere, McGuire et al. (2001) used four different models to explore different ecosystem dynamics. There are many more studies in this area that cover various different technical models to explore a balanced system. Many focus on surveying the natural systems present in different locations. None look to develop benchmarks to define limits around human activity, such as building and construction within cities.

2 METHOD

The method in this paper was selected to provide a high-level quick indication of the feasibility of green areas being used to offset upfront embodied carbon of new construction. The data sources and equations provided simplify the analysis to identify what scale would be most appropriate for future research using more detailed methods.

2.1 Calculating Carbon Sequestration Potential

To gauge the approximate carbon offsetting potential of different areas within an urban environment, a simplified approach to measuring the carbon sequestration potential was applied. Average annual carbon sequestration values were collected from data bases within two tools (One Click LCA and Climate Positive Design) (table 1), selected due to both having a well referenced and verified data sets. These values were then multiplied by the areas of different urban and peri-urban locations within the case study city, in order to model the total offsetting potential. Both tools were used to assist in calculating the quantities of different planting scenarios.

Table 1: Carbon sequestration/intensity of land use types

Land Use Type	Average annual carbon sequestration	Source
Wetland	2.445 $kgCO_2/m^2$	Climate Positive Design
Pine tree	47.84 $kgCO_2$/plant	One Click LCA
Grass, minimal management	-0.035 $kgCO_2/m^2$	Climate Positive Design
Grass, intensive management	-0.196 $kgCO_2/m^2$	Climate Positive Design
Shrub mix	2.25 $kgCO_2/m^2$	Climate Positive Design
Large deciduous tree	96.12 $kgCO_2$/plant	Climate Positive Design
Medium deciduous tree	43.52 $kgCO_2$/plant	Climate Positive Design

2.2 Offsetting Embodied Carbon Through Five Different Site Boundaries

This paper reports on the exploration of five different scales of boundary conditions, or 'site', to explore the carbon sequestration potential of available green areas to be used as an offset for the embodied carbon emissions of new construction (using equation. 1). These scales include: a building, a city block, the central business district (CBD), city boundary, a sample of the city within the wider regional context.

Equation 1

$$Total\ Sequestered\ carbon\ per\ year = Area \times Annual\ carbon\ sequestered\ carbon \quad (1)$$

2.3 Creating a Carbon Budget From Available Areas to Achieve Zero Emissions.

To calculate how long a carbon sequestering green area will take to offset the upfront carbon emissiosns of buildings, equation 1 was used to calulcate the number of years until net zero. Building carbon intensity ($kgCO_2/m^2$) values were used to estimate a building's business as usual carbon emissions in 2020 versus a building that met the 2030 reduction target. The values of 1000 $kgCO_2/m^2$ and 600 $kgCO_2/m^2$ were sourced from the LETI Climate Emergency Design Guide (LETI 2020). At the two smallest scales the tests explored how long it would take a carbon sequestering green area to offset the upfront embodied carbon of a 6000 m^2 building.

Equation 2

$$Years\ to\ reach\ net\ zero = \frac{(building\ carbon\ intensity \times floor\ area)}{Total\ sequestered\ carbon\ per\ year} \quad (2)$$

At the three larger scales the total carbon sequestered was used to calculate the area of new construction (m2) at the two building carbon intensities from LETI, (equation 3).
Equation 3

$$Area\ of\ new\ construction = \frac{Total\ Sequestrated\ carbon}{Building\ carbon\ intensity} \quad (3)$$

To calculate what the carbon budget could be if the carbon sequestering green area was the only form of offset available to the building, equation 4 was used. The carbon budgets are calculated in $kgCO_2/m^2$ to be compared to the building carbon intensity values from LETI's Climate Emergency Design Guide.

Equation 4

$$Carbon\ Budget\ = \frac{(Total\ Sequestered\ Carbon \times 60\ Year\ Serivce\ Life)}{Building\ Area*} \quad (4)$$

*Building area for tests was set to 6000 m^2

2.4 Caste Study: Christchurch, New Zealand

Christchurch was selected as a case study to test the integration of carbon offsetting strategies at five different scales. Christchurch is a city in the South Island of New Zealand with a population of 381,500 people. In 2010 and 2011 the city experienced several large earthquakes that resulted in loss of a large proportion of the city's residential and non-residential building stock. In several suburbs, parcels of land post-quake was deemed not suitable for new construction and form what is now known as the 'red zone'. A significant proportion of the central city has been rebuilt in the last decade. However, with no regulation for embodied carbon in New Zealand, this rebuild has likely contributed to a large quantity of carbon emissions. Loss of building stock due to some form of natural disaster is argued as likely to become more frequent due to climate change. Large loss of building stock requires rapid regrowth to supply housing and places to work for the people who live within the region. As rapid regrowth has the potential to increase emissions, due to the increased demand for building materials, it is important for cities to consider integrating strategies to offset these emissions.

3 LIMITATIONS

The study is limited by the variables available in the case study, whereby results may not be directly applicable to another city. Further the simplification of the calculation also limits the precision of the results.

4 RESULTS

The following sections present results that explore the feasibility of achieving a net zero outcome across different scales or definitions of 'site'. The use of a simplified calculation method limits the precision of the results, however these are only intended to provide an indication of which scale is the most feasible.

4.1 Building Scale

To integrate carbon sequestrating areas into the design of a building, two biophilic strategies of a green façade and a green roof were used on a 6000m^2 building. For the green façade, the building (fig 1, left) was designed to be 10 stories tall with a green band of plants wrapping each floor. The band was cantilevered 1.5m off the building's façade. This strategy created 1406m2 of area that could be planted with shrubs. It is assumed that the plants could grow on all orientations and that area represents the maximum planting area. This area is 2.3 times larger than the footprint of the building, 600m^2. For a building with a green roof (fig 1, right), the building was made 2 stories tall to create an area of 3000m2 that could be used. This area is equal to the footprint of the building.

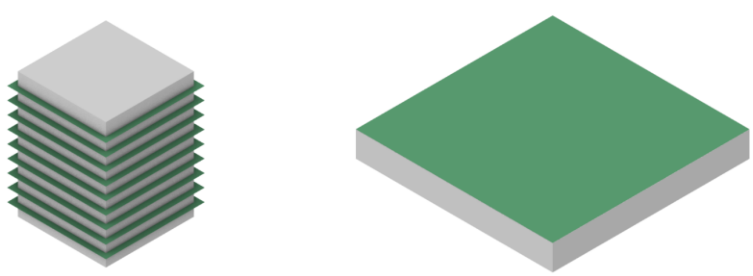

Figure 1: Tall building with green façade (left), and short building with green roof (right)

Table 2: Building Scale Results

Strategy Tested	Carbon Sequestration Type	Carbon Sequestered ($kgCO_2$)	Years to offset a building with 1000 $kgCO_2/m^2$	Years to offset a building with 600 $kgCO_2/m^2$	Built GFA offset at 1000 $kgCO_2/m^2$	Built GFA offset at 600 $kgCO_2/m^2$	Upfront Carbon budget $kgCO_2/m^2$
Green Facade	Shrubs	3157	1900	1140	3.16 m^2	5.26 m^2	32
Green Roof	Shrubs	9766	614	389	7.77 m^2	16.27 m^2	98

4.2 City Block Scale

At the city block scale a sample area of a standard block that had an existing green street was used to calculate the carbon sequestration potential. The quantities of planting areas and types were gathered through measuring the areas using google earth and counting the trees using street view and aerial imagery. This test explored if the upfront embodied carbon emissions from the same 6000m2 building could be offset by the same quantity found within the city block. The results found that the total sequestered carbon from the different planting types was not enough to offset the building at either a business-as-usual carbon intensity of 1000 $kgCO_2/m^2$ or at the 2030 goal of 600 $kgCO_2/m^2$. Reversing the equation, if the planting was to be sufficient to support 6000m^2 of new building for a 60 year period, the maximum carbon intensity could be only 109 $kgCO_2/m^2$.

Figure 2: City Block sample from Christchurch CBD

Table 3: City Block Scale Results

Strategy Tested	Carbon Sequestration Type	Carbon Sequestered ($kgCO_2$)	Years to offset a building with 1000 $kgCO_2/m^2$	Years to offset a building with 600 $kgCO_2/m^2$	Built GFA offset at 1000 $kgCO_2/m^2$	Built GFA offset at 600 $kgCO_2/m^2$	Upfront Carbon budget $kgCO_2/m^2$
Green Streets	Large Tree	3653	1643	985	3.65 m^2	6.09 m^2	37
	Medium Tree	2872	2089	1253	2.87 m^2	4.79 m^2	29
	Wetland	4544	1320	792	4.54 m^2	7.57 m^2	45
	Grass, minimal management	-200*	-	-	-	-	-
oveall	**-**	**10870**	**552**	**276**	**11.06** m^2	**18.45** m^2	**109**

*value contributes to carbon emissions and has no sequestration capability

4.3 Central Business District Scale

The central business district (CBD) of Christchurch is defined by four avenues. Within this boundary is a large urban park called Hagley Park. At this scale the test explored what quantity of new construction at different building carbon intensities could be supported by the carbon sequestering capabilities of the park. Approximate areas of grass and quantities of trees were gained from aerial imagery (fig 3) and maps. The modelling showed that the maintenance level of the grass to facilitate sports fields emits carbon rather than sequestering carbon. The rate of emissions is the same as a building of area 494 m^2 at 1000 $kgCO_2/m^2$, or of 823 m^2 at 600 $kgCO_2/m^2$ per year. However, the net result of the park was still climate positive due to the tree coverage in part of the park. Tree planting the whole area of the size of Hagley Park could balance the upfront embodied emissions of **15,077 m^2** new construction per year with a carbon intensity of 1000 $kgCO_2/m^2$ or **25,128 m2** at the 2030 goal of 600 $kgCO_2/m^2$ (Table 3).

Figure 3: Central Business District

Table 4: Central Business District Scale Results

Strategy Tested	Carbon Sequestration Type	Carbon Sequestered ($kgCO_2$)	Built GFA offset at 1000 $kgCO_2/m^2$	Built GFA offset at 600 $kgCO_2/m^2$
Urban Park	Large Tree	4,806,000	4,806 m^2	8,010 m^2
	Medium Tree	10,270,720	10,270 m^2	17,118 m^2
	Grass, Intensive Management	-494,047*	-494 m^2	-823 m^2
OVERALL		**15,076,720**	**15,077 m^2**	**25,128 m^2**

*value contributes to carbon emissions and has no sequestration capability

4.4 City Scale

After the 2011 earthquakes, a large area, known as the ‘red zone’ (shown in red in fig 4), within the city was deemed not suitable for building. The ‘red zone’ no longer has any buildings on it. The zone naturally follows the Avon River and connects onto existing wetland areas that currently exist within the city (shown in purple in fig 4). Williams (2005) documented the native planting ecosystems of the Christchurch city area and showed that the red zone is a preexisting wetland. This paper tested what potential the ‘red zone’ could have in offsetting the upfront embodied emissions from new construction if converted back to wetland. The results found that, as a wetland, the ‘red zone’ could sequester almost 3 times as much carbon as the existing area of wetland. The combination of both could offset the upfront embodied carbon emissions per year from new construction of 19,348 m^2 or 32,247 m^2 at 1000 $kgCO_2/m^2$ or 600 $kgCO_2/m^2$ respectively.

Figure 4: City scale showing the red zone and existing wetland (purple)

Table 5: City Scale Results

Strategy Tested	Carbon Sequestration Type	Carbon Sequestered ($kgCO_2$)	Built GFA offset at 1000 $kgCO_2/m^2$	Built GFA offset at 600 $kgCO_2/m^2$
Urban Wetland	Wetland	14,936,377	14,936 m^2	24,894 m^2
Existing Wetland	Wetland	4,412,038	4,412 m^2	7,353 m^2
OVERALL		**19,348,415**	**19,348 m^2**	**32,247m^2**

4.5 Regional Scale

At the regional scale, this paper tested two strategies to add carbon sequestering landscapes to offset the upfront embodied carbon emissions of new buildings. The first was to add a green border of approximately 2km wide alone the major rivers (shown in purple in fig 5). These borders act as an extension of pre-existing trees that already grow along the river's edge. The second was to introduce a green border of approximately 1km wide either side of the major highway south of the city (shown in blue in fig 5). The green borders along the river were tested as pine forests (not native to New Zealand, but fast growing) and the border along the highway was tested as a mixed tussock (perennial grass) and medium trees (closest match to the size of a native tree). The results show that these offsetting tests could offset a significant amount of upfront embodied carbon emissions (table 6 – 1.6 to 2.7 million square meters of new construction).

Table 6: Region Scale Results

Strategy Tested	Carbon Sequestration Type	Carbon Sequestered ($kgCO_2$)	Built GFA offset at 1000 $kgCO_2/m^2$	Built GFA offset at 600 $kgCO_2/m^2$
Green River Border (North)	Pine Forest	414,493,572	414,494 m^2	690,823 m^2
Green River Border (North)	Pine Forest	955,269,780	955,270 m^2	1,592,116 m^2
Highway Green Border	Perineal Grasses (tussock)	88,193,003	88,193 m^2	146,988 m^2
Highway Green Border	Medium Tree	193,358,161	193,358 m^2	322,264 m^2
OVERALL		**1,651,314,516**	**1,651,315 m^2**	**2,752,191 m^2**

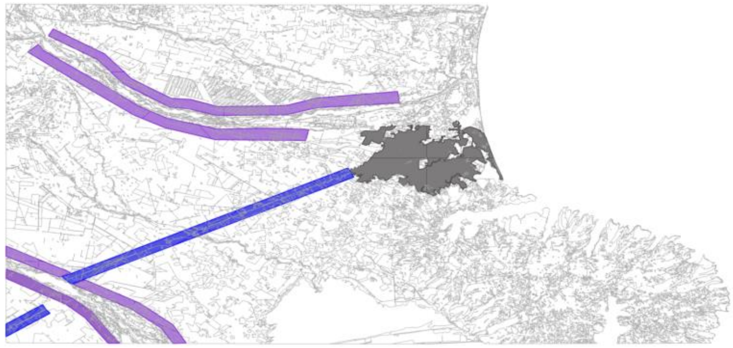

Figure 5: Region sample showing the city footprint (grey) and proposed offset areas

5 DISCUSSION

This paper explores the effect of biophilic strategies to offset upfront embodied carbon emissions associated with the construction of buildings. Simple green planting strategies, which are often the core first step in a biophilic design process, have the potential to offset a significant amount of building whilst achieving a net zero carbon urban system. Small scale biophilic interventions at the site level allow little scope for genuine net zero performance. However, shifting scales to an urban or even peri-urban level offers far more scope. The lesson is that if looking to design a building to achieve the soft social benefit to people, one can also model the 'hard' benefit to the planet by looking beyond the site to its broad urban context.

5.1 Region

The regional scale appears to offers the most useful net zero system boundary. Examining regions in this manner allows the setting of building carbon intensity limits based on the amount of carbon that could be sequestered within the various types of planted area within the region. From a purely simplified quantitative perspective of balancing emissions to the atmosphere with the capability to draw the carbon back down, the exercise appears successful. However, this modelling can only outline what area per planting type is required. To answer the question of where, requires a social perspective to position the planted areas to allow people to interact with them. Following Wang et al.'s (2018) 'objects of care' approach, allowing people to have some form of engagement with the planted areas is argued to increase positive feelings towards taking action to mitigate climate change. Not only does one achieve the biophilic approach benefits of greening the city, but through this one achieves buy-in to the carbon offset approach as well. Making the people 'feel good' about integrating carbon sequestering landscapes into the region has potential to make the financial cost of offsetting carbon feel like less of a burden as the investment is local and visible. The planted areas in the case study were along relatively short stretches of highway and along the banks of the alps to the ocean rivers that run through this region.

5.2 City

At the city scale, the case study city has a unique area arising from a risk analysis looking at ground conditions under buildings across the city following the 2011 earthquakes – the 'red zone'. Williams (2005) identified that the planting systems in the red zone prior to the building developments had wetland characteristics. Returning the land to this natural form could sequester 14,936,377 kg of carbon dioxide per year, which is only 1% of the potential carbon sequestration capacity of the region. However, the area naturally weaves its way through the city and would be easy for people to engage with. Beatley (2016) recorded a benefit of increased health and well-being for people who live close to areas like this. This inclusion of biophilic assessment into carbon sequestration modelling allows a more holistic urban scale modelling of improvements in health and well-being. In the process this addresses holistically goal 3 of the United Nations Sustainable Development Goals (SDGs), alongside sustainable cities and communities (goal 11), responsible consumption and production (goal 12), climate action (goal 13), and protect, restore, and promote life on land (goal 15) (United Nations 2015).

5.3 Central Business District

The ‘Red zone’ is unique to the case study city, Christchurch. While it is plausible to convert it to a wetland, and other cities will have their own equivalent special areas that can be readily converted to sequestration, the conversion of a more established green urban area, like Hagley Park, examines the more typical urban challenge. Reeve et al (2015) argue that from a biophilic perspective, a large accessible ‘green’ area can have a very positive impact on the people who live within the city . Modelling carbon sequestration of an existing park in Christchurch revealed that the maintenance required for the large area of lawn would not sequester carbon, and instead contribute to carbon emissions to the atmosphere. Christchurch is like many other cities in possessing large central green areas as landmarks within the city. The Hagley Park example brings into question whether the biophilic health and well-being benefits of large quantities of lawn and sports fields that need to be regularly maintained should at least be offset by providing a mix of another type of planting, or whether there are similarly useful green surfaces that require less carbon intensive maintenance.

5.4 City Block and Building

Reducing the definition of the 'site’ for carbon sequestration associated with a building development to the city block scale allowed testing the potential of using the planted landscape along the Avon River to balance the impact of a new building added to the block. This river is a feature of the Christchurch city case study, and is clearly not representative of all cities. It adds extra green area at the city block level that is not available even in all Christchurch City blocks. Even so, it did not provide a viable sink for a single building's upfront embodied carbon emissions. These upfront emissions would have to be on sixth of those targeted by LETI (REF) for 2030 for this small sequestration capacity to be viable. At the individual building scale the carbon sequestering potential of two biophilic strategies was tested: green façade and green roof. The modelling demonstrated that both planting options were unrealistic for sustaining a net zero system. Calculating carbon sequestration as a budget which limits the ‘site’ to a single building or a city scale severely limits the size of building or material palette of new construction.

6 CONCLUSION

A simplified method for modelling the carbon sequestration potential of different green areas, has provided a high level understanding on the plausibility of local offsetting of the embodied carbon emissions associated with the construction of buildings. The case study demonstrates how rethinking the definition of ‘on-site’ when looking at carbon emission offsetting can identify the carbon sequestration potential of different peri-urban green areas. The quantitative assessment demonstrated that sequestration of carbon at the building or even the city block level is likely impossible. At the urban or peri-urban scale there is great potential for carbon sequestration that is of a scale that can cope with upfront embodied carbon emissions. This provides a viable alternative to purchasing carbon credits for planting in remote locations or countries. More significantly, this expansion of site to the local region offers the opportunity to develop not just the sequestration function but is likely to lead to biophilic health and well-being improvements and community buy-in to the whole sequestration process. A social understanding was drawn from a wide review of existing literature to guide the placement of green areas at the largest and smallest scale. The consensus of this literature review was that there is an intangible benefit to human wellbeing from the inclusion and care of natural environments within urban and peri-urban areas. This identified the advantages that arise from applying a qualitative lens when considering the integration of carbon offsetting green spaces within urban contexts. In essence, this paper has found that; 1) a quantitative approach can inform a designer of how much area will be required to offset a building’s upfront embodied carbon, 2) a qualitative approach using strategies drawn from biophilia can guide a designer on the placement of the green areas, and 3) the social understanding validates that this holistic approach is good for people and could help motivate them to make the positive change we so desperately need. Future work could apply the feasibility study to investigate the potential for other cities in different countries.

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FIONA SHORT, Principal & Lead of Sustainability, is a passionate and skilled registered architect with well-rounded knowledge in many aspects of design. She joined Warren and Mahoney's Christchurch office in 2011 and was appointed Associate in 2017. Project involvement has ranged from master planning to bespoke residential designs with an emphasis on feasibility and concept design development. Fiona has a focus and understanding on environmental sustainability, urban design and social impact, and her projects have included Little Company of Mary housing project (NZIA National Award 2016); East Frame development proposals in Christchurch; several house designs; and part of the teams on the PWC Building, Lincoln Hub project and health master planning projects. Fiona is a leader in sustainable design thinking in Warren and Mahoney and a regular speaker at industry events. She strives to find the best and most appropriate solution for every project and client.