Landscape architects need to address life cycle greenhouse gas emissions in designs – A case study near Sydney, Australia

Sareh Moosavi[1], André Stephan[2] and Martin O'Dea[3]

[1] *Belgian Fund for Scientific Research (F.R.S.-FNRS), Brussels, Belgium*
[1, 2] *Université Catholique de Louvain, Brussels, Belgium*
{sareh.moosavi[1], andre.stephan[2]}@uclouvain.be,
ORCID-0000-0002-4819-2772[1], ORCID-0000-0001-9538-3830[2]
[3] *CLOUSTON Associates – a division of Beveridge Williams, Australia*
mod@clouston.com.au

Abstract: It is often believed that green infrastructure assets are net carbon sinks and this may have contributed to the lack of consideration of embodied greenhouse gas emissions by landscape architects. However, these embodied emissions cannot be ignored. This paper aims to demonstrate the significance of life cycle greenhouse gas emissions in park design and the need for landscape architects to address them. We use a hybrid life cycle inventory approach to quantify the life cycle embodied greenhouse gas emissions of the 26 000 m² Willowdale park, a greenfield development near Sydney, Australia. We take into account operational emissions associated with lighting, operating barbecues and mowing, as well as carbon sequestration in soils and trees. All original quantities are sourced from primary data. Results show that life cycle embodied greenhouse gas emissions are significant, at 1 419 tCO2e over 50 years (55 kgCO2e/m²). Initial embodied greenhouse emissions from the day the park opened represent almost 73% of life cycle emissions. It takes 47-48 years for the trees and the soil to sequestrate enough carbon to offset embodied and operational emissions. In other terms, for almost the first five decades, this park remains a net carbon emitter. These results demonstrate the need for landscape architects to understand embodied emissions in construction materials. Equally, they need to plant as many climate-resilient trees that sequestrate enough carbon to offset embodied greenhouse gas emissions in shorter timeframes. Using a detailed and comprehensive life cycle assessment model is critical to achieving climate positive outcomes.

Keywords: Embodied carbon; Carbon Sequestration; Life Cycle Assessment; Landscape Architecture.

1. Introduction

There is an urgent need to reduce global greenhouse gas emissions (GHGE) and to limit global warming to 1.5°C in 2100 to meet the Paris Agreement. The built environment is a major source of GHGE with up to 75% contribution (UN-Habitat, 2011; Anderson *et al.*, 2015). Actions to reduce GHGE has largely focused in the engineering and building sectors (Andrić *et al.*, 2019). However, the way we plan and design

Architectural Science and User Experience: How can Design Enhance the Quality of Life: 55th International Conference of the Architectural Science Association *2022,* P. Izadpanahi and F. Perugia (eds.), *pp. 405–414.*

our landscapes (i.e. green and blue infrastructures, parks and urban open spaces) has to transform if we want to address global challenges such as climate change. Constructed urban landscapes and green-blue infrastructure are identified as most promising in maximizing opportunities for both climate adaptation and mitigation strategies (Kabisch *et al.*, 2016; Sharifi, 2021). Landscape architects are responsible for designing these spaces, and they need to ensure that their design interventions do not breach the ecological and planetary boundaries. When it comes to designing for climate change, landscape architects' design activities often focus on adaptation through the design of nature-based flood control features (Moosavi *et al.*, 2021), cool green public open spaces (Langenheim *et al.*, 2020), and community-scaled productive landscapes (Bunster-Ossa, 2019). However, adaptation without reducing the sources of GHGE, cannot be sustained. Adaptive efforts would need to constantly meet new benchmarks as the climate continues to change (Grafakos *et al.*, 2018; Hurlimann *et al.*, 2020). To do so, the profession should strive to better understand embodied GHGE, carbon metabolism and operational GHGE from parks and other green infrastructure.

Landscape architects need to be able to understand and account for the net life cycle GHGE associated with design decisions. This includes increasing their knowledge about carbon footprints of materials to avoid using emission intensive materials such as concrete, steel, dimension stone and kiln dried timber, as well as understanding that intensively managed and fertilised lawns can be net emitters, along with the effects of fossil fuel powered maintenance equipment. This needs to be balanced against opportunities to incorporate enough trees that can sequester these initial embodied emissions. It is important to ensure that trees will be large and healthy 50 years into the future. They will need to have sufficient interconnected soil volume, and reliable water from passive irrigation or other sources. With rapidly shifting bioclimatic zones, landscape architects also need to carefully consider species selection that will survive in the projected climatic zone in 2100.

The idea of low carbon landscapes is not new in the discipline of landscape architecture (see Pocock (2007)). However, it has increasingly gained traction in academic literature (Moosavi *et al.*, 2022; Nikologianni *et al.*, 2022). Methodologies for embodied GHGE calculations from a landscape architectural lens are only emerging. Most life cycle assessment tools primarily cater for buildings and hardscape emissions. There are very few tools that can be used to evaluate the emissions draw-down of landscapes. The most common method adapted for green infrastructure and nature-based solutions is carbon footprint analysis, which is an established method for systematically quantifying carbon sinks and sources throughout the lifetime of goods and services (Strohbach *et al.*, 2012a; Romanovska, 2019). There is a need to advance capacity in landscape architecture to consider environmental footprints of design interventions throughout their life cycle, and this calls for tailored methodologies and tools that can be used and adopted by landscape architects. In a recent study, Nikologianni *et al.* (2022) have reviewed and discussed some of the pioneering carbon calculation tools used in landscape architecture, including the most recent Climate Positive Pathfinder Tool developed by landscape architect Pamela Conrad in California. The pathfinder is a design and planning tool that accounts for embodied emissions from construction, carbon sequestration from trees, shrubs and soil, as well as operational emissions. Nikologianni *et al.* (2022) conclude that there is a need for more tools that are better tailored to the needs of landscapes architects, as well as training, guidance and professional development to enable landscape practitioners to use whole-life carbon approaches.

This paper aims to demonstrate the need for landscape architects to engage with life cycle GHGE in their design decisions. Using a single case study approach, this study quantifies the net life cycle GHGE of an urban park in Sydney, Australia. Detailed design documents from the design team in charge of the project were obtained, along with the detailed bill of quantities of all materials used in the park, all land-use changes and all vegetation planted. Using the EPiC database (see Section 2.3), we quantify the life cycle embodied GHGE of all materials. The carbon sequestration in soils, and the proposed trees were estimated based upon their species, over a 50 year time frame.

2. Method

2.1. Overall research approach

Figure 1 depicts the overall research approach adopted in this paper. Firstly, data on the park is collected, including a detailed bill of material quantities, land-use changes, and trees planted. Secondly, the life cycle embodied GHGE associated with materials are calculated. This is followed by the calculation of life cycle operational GHGE, notably lighting. The fourth step involves the quantification of the life cycle carbon sequestration in trees and soils before calculating the net life cycle GHGE of the case study park in the final step. Results are analysed per type of emissions and hot spots are identified.

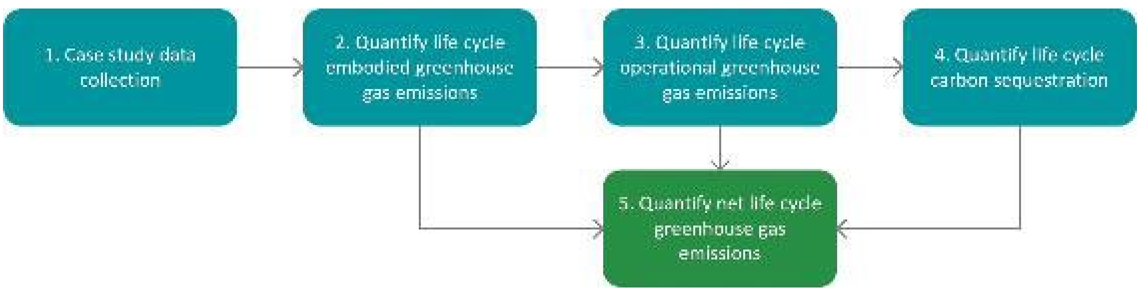

Figure 67: Overall research approach

2.2. Case study description

We use a single case study approach as our main research method (Yin, 2018, p. 49-50). The case study is the Willowdale park built in 2017 and located near Sydney, New South Wales, Australia. Figure 2 depicts the masterplan of the park and Table 1 summarises its main characteristics.

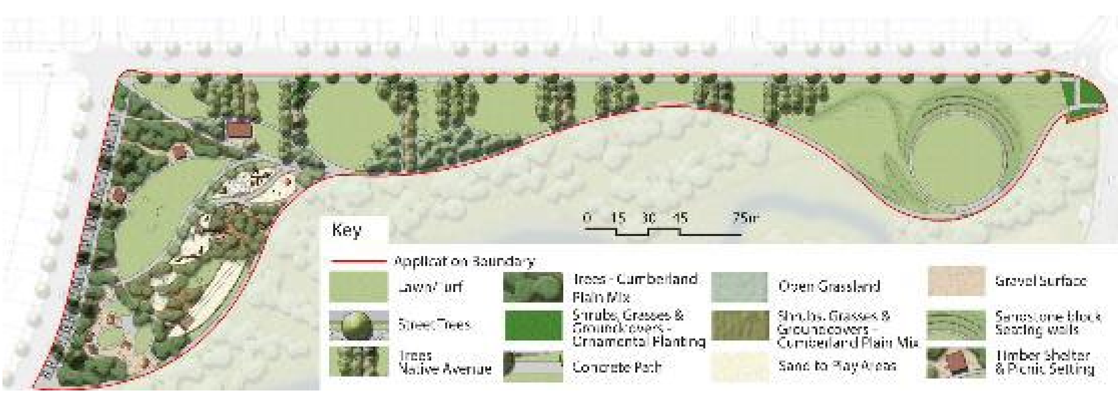

Figure 68: Masterplan of Willowdale Park. Source: CLOUSTON Associates

The park comprises a large playground with sandpits, tensile shade structure, barbecue areas and public toilets. The rest of the park consists of large areas of turf with native trees planted in linear patterns. Sandstone is used extensively in the park design, both in the playground area as well as for the amphitheatre and waterplay area (Figure 3). A total of 405 trees were planted, of which 402 are from six species of the Eucalyptus genus. The Willowdale park was constructed on former farmland in a suburban area.

Figure 69: View from the waterplay area and view hill towards the playground

Table 37: Case study characteristics and quantities of main materials

Characteristic	**Value**
Park name	Willowdale
Location	33.980571 S 150.809571 E, New South Wales, Australia
Year built	2017
Period of analysis	50 years (until 2067)
Total area	~26 000 m²
Lawn area	12 820 m²
Impervious area	8 730 m² (33.5%)
Mass planted area (shrubs, plants, etc.)	4 370 m²
Number of planted trees	405
Mass of concrete (kg)	2 950 524 kg
Mass of sandstone (kg)	581 095 kg
Mass of steel (kg)	74 669 kg
Mass of timber	1 462 kg

2.3. Quantifying life cycle embodied greenhouse gas emissions

Life cycle embodied GHGE associated with all construction materials used in the park are calculated using a hybrid life cycle inventory approach (Crawford *et al.*, 2018) and relying on coefficients from the EPiC database (Crawford *et al.*, 2019b; 2021). This ensures that system boundaries across supply chains are complete. We use a static approach, assuming that embodied GHGE associated with material replacements in the future have the same intensity as today. Only stages A1, A2 and A3 (within the framework of European Standard 15978 (2011)) are taken into account in this study, using a cradle-to-gate system boundary. This means that the transport of materials from factories to the site is not taken into account, nor the construction process itself.

Equation 1 is used for the calculation of life cycle embodied GHGE. In summary, we go through all the construction materials used in the park and multiply them by relevant GHGE coefficients from the EPiC database. The triple sigmas in the equation represent the nested nature across built environment scales, based on the Nested Phoenix model we are using (see Stephan *et al.* (2022)). The replacement of materials over time is also considered based on average service lives. It is important to note that embodied emissions associated with the playground equipment used in the park were not considered in this paper. Furthermore, as the EPiC database does not contain a coefficient for sandstone, a major material in this project (>580 t), we used a process figure from the Athena Database and scaled it up assuming the same truncation error as for dimension stone, a similar product in the EPiC database.

$$LCEGHG_p = \sum_{a=1}^{A}\sum_{e=1}^{E}\sum_{m=1}^{M}\left(Q_{m,e,a,p} \times GHGC_m\right) + \sum_{y=CY_p}^{TH}\sum_{a=1}^{A}\sum_{e=1}^{E}\sum_{m=1}^{M}\delta_{m,e,a,p,y} \times \left(Q_{m,e,a,p} \times GHGC_m\right)$$

$$\delta_{m,e,a,p,y} = \begin{cases} 1 \Leftrightarrow \frac{(y-CY_p)}{SL_{m,e,a}} \in \mathbb{Z}^+ \\ 0 \Leftrightarrow \frac{(y-CY_p)}{SL_{m,e,a}} \notin \mathbb{Z}^+ \end{cases} \quad \forall\ CY_p < y \leq TH \qquad (1)$$

Where: $LCEGHG_p$ is the life cycle embodied GHGE of park p in $kgCO_2e$; A is the total number of assemblies in park p; E is the total number of elements in the assembly a; M is the total number of materials in the element e or the assembly a; $Q_{m,e,a,p}$ is the quantity of material m in the element e in the assembly a in the park p (e.g. m^3 of concrete); $GHGC_m$ is the hybrid GHGE coefficient of material m in $kgCO_2e$ per functional unit of material; TH is the time horizon of the analysis, e.g. 2050; CY_p is the construction year of park p, e.g. 2007; $\delta_{m,e,a,p,y}$ is a modified Dirac delta function; $C_{m,e,a,p}$ is the cost of the material m used in element e, in assembly a, in park p, in AUD; and $SL_{m,e,a}$ is the service life of the material m as used in element e and assembly a, in years.

2.4. Quantifying life cycle operational greenhouse gas emissions

Life cycle operational GHGE are obtained by summing the emissions of all end-uses in a given park, e.g. lighting. For each end-use in the park, we multiply the wattage rating of the end-use by the time it is used over one year. We convert that delivered energy to GHGE by multiplying it by a GHGE factor that accounts for Scope 2 and 3 emissions in the electricity generation supply chain (Department of Industry, 2021). We use a static approach and multiply these annual emissions by the period of analysis (time horizon – construction year of the park). This is deemed to have minimal consequences on this study as operational GHGE are very small as compared to embodied emissions. Equation 2 is used to calculated life cycle operational GHGE. Practically, we considered electricity use for lighting, and the electric barbecues on site as well as a diesel mower.

$$LCOPGHG_p = \left(TH - CY_p\right) \times \sum_{e=1}^{E} R_{e,p} \times T_{e,p} \times 3.6 \times 10^{-6} \times EF_e^S \quad (2)$$

Where: $LCOPGHG_p$ = Life cycle operational GHGE of park *p* in $kgCO_2e$; *TH* and CY_p are defined in Equation 1; E is the total number of operational energy end-uses; $R_{e,p}$ = Wattage rating of end-use *e* present in park p, in W; $T_{e,p}$ = Average annual operating time of end-use *e* in park *p*, in hours; and EF^S_e = GHGE factor for the energy source S of the end-use *e* in $kgCO_2e/GJ^{DELIVERED}$.

2.5. Quantifying life cycle carbon sequestration in trees and soils

Carbon sequestration in trees and soils is quantified as per Equation 3, based on (Stephan *et al.*, 2022). The carbon sequestration model for trees is taken from the U.S. Department of Energy (1998). Carbon sequestration in soils is based on an average annual sequestration rate per m² (see Lindén *et al.* (2020) for an example). Carbon sequestrated in trees that die over time is not considered to be remitted as the fate of the tree is unknown decades into the future (it could be harvested and chipped for use as a soft surface in playgrounds). It is important to flag that we modified the survivability factor of trees in this study to better reflect the reality of the context, estimating that 90% of trees planted will survive in 50 years. Should the original factors be kept, only 21.8% of trees survive at that time horizon.

$$LCCS_p = \sum_{t=1}^{T} \sum_{y=PY_{t,p}}^{TH} SF_{t,y,p} \times ACS_{t,y,p} + \sum_{s=1}^{S} \sum_{y=LUCY_{s,p}}^{TH} A_{s,p} \times ACSLUC_{s,p} \times SF_y$$

$$SF_{,y} = \begin{cases} 1 \Leftrightarrow y \leq 2 \\ e^{\frac{-y}{8}} \Leftrightarrow y > 3 \end{cases} \quad \forall\ y \geq 0 \quad (3)$$

Where: $LCCS_p$ is the life cycle carbon sequestration of park *p* in kgC; *T* is the total number of trees in park *p*; $PY_{t,p}$ is the plantation year of tree *t* in park *p*; $SF_{t,y,p}$ is the survival factor of tree *t* at year *y* in park *p*, which is a function of its species, growth rate and age; $ACS_{t,y,p}$ is the annual carbon sequestration rate of tree *t* for year *y* in park *p*, in kgC/annum; S is total number of soil areas; $LUCY_{s,gi}$ is the year during which the land-use change of soil *s* occurred in park *p;* See Equation 1 for the definition of *TH*; $A_{s,p}$ is the area of soil *s* in park *p*, affected by land-use change, in m²; $ACSLUC_{s,p}$ is the annual carbon sequestration rate for soil *s* in park *p*, in kgC/(m²·a) and SF_y is a saturation function that decreases the annual soil sequestration rate, and is applied from year 3 onwards.

2.6. Quantifying net life cycle greenhouse gas emissions

The net life cycle GHGE of the park are obtained by summing the life cycle embodied and operational GHGE and subtracting the carbon sequestration, converted to emissions by using the ratio of the atomic mass of CO_2 (44) and C (12), as per Equation 4.

$$NLCGHG_p = LCEGHG_p + LCOPGHG_p - LCCS_p \times \frac{44}{12} \quad (4)$$

3. Results

Figure 4 shows the life cycle GHGE of the park. Overall, embodied GHGE dominated the life cycle GHGE profile representing 1 419 tCO_2e. Carbon sequestration in trees represented 1 950 tCO_2e at 50 years and soils absorbed carbon representing 153 tCO_2e at the same time. Operational emissions represented 27.2% of total emissions over 50 years, but this figure should be much smaller when considering decarbonising electricity grids, and embodied emissions will have a higher contribution. The net life cycle GHGE balance reaches zero after 47 years of the park's lifespan. The leap in embodied GHGE at year 30 in Figure 4 is due to the replacement of certain materials, which is equivalent to the preceding four years of sequestration.

Embodied emissions are driven by sandstone (38.5%), concrete 25 and 32 MPa (35.5%), structural steel (15%), gravel (1.7%), and high-density polyethylene (0.7%). The remaining 8.6% of the life cycle embodied GHGE are spread across 11 other materials, including hardwood and galvanised steel. Operational emissions are driven by lighting (62.7%) and the use of barbecues (35.2%). Mowing represented 2% of the total operational emissions, based on 3 hours of mowing per month.

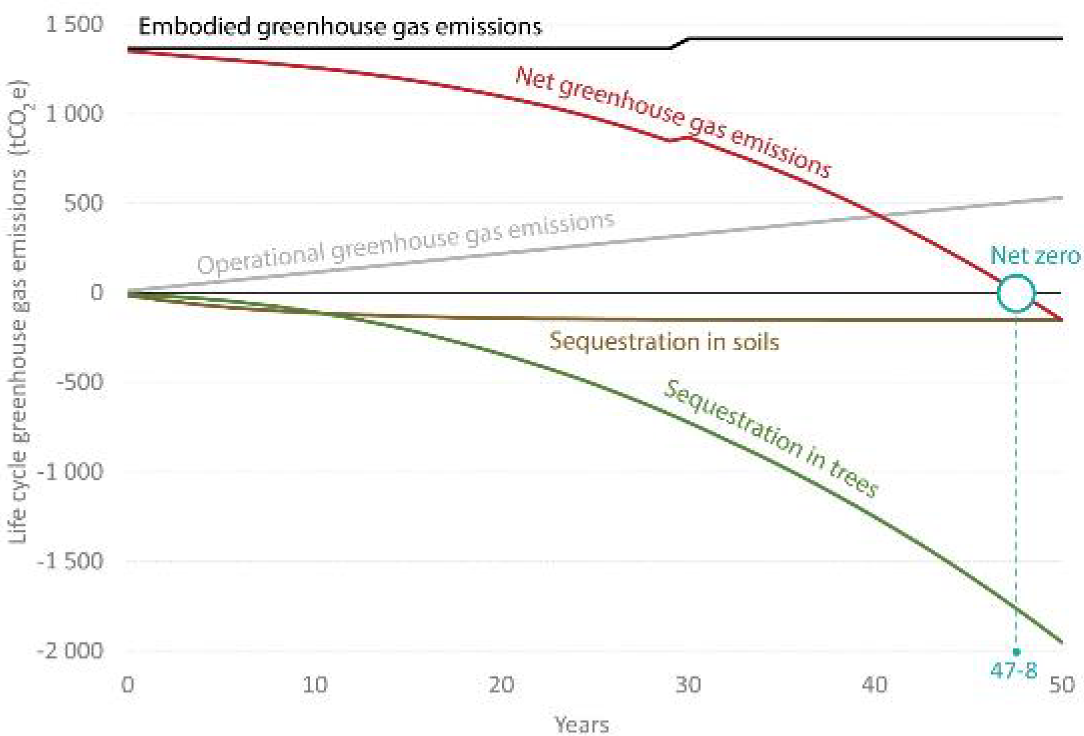

Figure 70: Life cycle greenhouse gas emissions profile of the case study park

4. Discussion and Conclusion

This study has quantified the net life cycle GHGE of a park in Sydney, Australia over 50 years and demonstrated their significance. For the first 40+ years of the life of the park, its net life cycle GHGE balance is largely positive, resulting in the net emission of 52, 46, 33, and 6 $kgCO_2e/m^2$ of park at years 0, 15, 30 and 45, respectively. It is only after trees grow enough to start sequestrating carbon at a significant rate that they start offsetting the embodied GHGE.

The significant amounts of embodied GHGE associated with a park clearly demonstrate the need for the landscape architecture discipline to consider them. There is currently a lack of consideration of life cycle GHGE in park design, notably embodied GHGE in construction materials. Given that sturdy and hardwearing materials are used in the park design, recurrent embodied GHGE represented 6% of initial embodied emissions, unlike in buildings where they usually represent 30-50% over 50 years, depending on material choices (Stephan and Crawford, 2014; Stephan and Athanassiadis, 2017). As such, landscape architects need to carefully choose their construction materials. The production of key materials such as concrete emit greenhouse gases. Other materials such as steel, aluminium and kiln dried timber, have high emissions due to the current reliance on fossil fuels for their manufacture. These emissions will remain in the atmosphere for decades and the park soil and trees will need decades to sequestrate enough carbon to reach carbon neutrality (around 40 years in the case of this park).

An important contribution of this study is the reliance on a hybrid life cycle inventory approach for the quantification of embodied GHGE. Had process-only data been used instead, the life cycle embodied GHGE would be 958 instead of 1 419 tCO_2e (-32.5%) and the year at which the park would reach 'carbon neutrality' would be moved back by 8 years, to year 40 instead of year 48. This demonstrates the need to use hybrid life cycle inventory data in order to avoid underestimating embodied emissions and overestimating the capacity of the park in acting as a net carbon sink.

In addressing the climate emergency, landscape architects have access to a number of emerging tools to guide design decisions. These include the Climate Positive Pathfinder application and the EPiC database. These tools help empower landscape architects to understand GHGE and make informed decisions on material choices, plant selection and specifications. While generic materials assessments is helpful, there is a need for more data from suppliers and manufacturers to provide consistent, transparent and systemically complete environmental product declarations (EPDs) for specific products. These would provide designers with a more refined choice of materials. However, current EPDs have such variability in their data that they can be unreliable (Resalati *et al.*, 2019). On the sequestration side, much more data and research are required to better understand Australian plants and their long-term performance. In particular, more data is needed on how different trees in urban situations perform under a changing climate. With only 28 years to meet net zero under the Paris agreement, there are research opportunities to evaluate the real sequestration of trees planted 28 years ago in 1994.

As in any scientific inquiry, this study suffers from a number of limitations. Firstly, results are applicable to the case study park only. Design specifications including material compositions, land-use and tree plantations can vary widely between park designs, directly affecting life cycle GHGE. Second, we excluded materials used in the playground equipment (e.g. swings, slides, diggers, etc.). Third, we used a process-based hybrid analysis focusing on a cradle-to-gate approach and did not account for non-material inputs required to build the park. These can represent around 20-40% additional embodied GHGE when it comes to residential buildings (Crawford *et al.*, 2019a) and probably a similar figure when applied to parks. Fourth, minor shrubs and plants were modelled as native grassland, but they may sequestrate more or less carbon depending on the species. Fifth, we used a modified survivability rate in this study but ideally multiple scenarios of trees survivability need to be explored as this significantly impacts the carbon sequestration potential of parks, as also demonstrated by (Strohbach *et al.*, 2012b). Future research will focus on extending the study to other case studies for comparison, including stages A4 and A5 as well as the input-output remainder in embodied GHGE calculations, and further refining the carbon sequestration calculations.

Landscape architects have a unique opportunity to address the climate crisis through good design. While parks can provide cool, green, and shady spaces that people love and enjoy, as well as habitats for other species, landscape architects must be mindful of the projects GHGE. With up to ~75% of greenhouse gases over 50 years having been emitted the day parks are opened, climate mitigation through a reduction in embodied and operational carbon and maximising sequestration is essential to a liveable future. The profession is moving in this direction with the recently published Climate Positive Design Action Plan for Australian landscape Architects, by the Australian Institute of Landscape Architects (O'Dea *et al.*, 2022). The American Society of Landscape Architects (ASLA) is also publishing an action plan in mid-November 2022. There is a growing understanding of the embodied greenhouse gasses in construction and engaging with industry to drive low carbon products. This points to better outcomes for a liveable planet. The data and tools are available. Agency and know-how need to follow.

Acknowledgements

Sareh Moosavi is funded by a Postdoctoral Research Fellowship from the Belgian Fund for Scientific Research (F.R.S.-FNRS) under grant number (FC.43179). The research has also received funding from the Belgian Fund for Scientific Research (F.R.S.-FNRS) *Mandat d'Impulsion Scientifique* grant (F.4547.21). The authors would like to thank Clouston Associates– a division of Beveridge Williams, Australia for providing the primary data for the case study.

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