LCM in urban planning for diminishing GHG. Case study on concrete sidewalks.

Jordi Oliver-Solà[1,2]*, Alejandro Josa [3], Xavier Gabarrell [1,4], Joan Rieradevall [1,4]

[1] SosteniPrA (UAB-IRTA). Institute of Environmental Science and Technology (ICTA). Universitat Autònoma de Barcelona (UAB). 08193 Cerdanyola del Vallès, Barcelona, Catalonia, Spain.
[2] Inèdit Innovació SL, UAB Research Park, Catalonia, Spain.
[3] Department of Geotechnical Engineering. Technical University of Catalonia (UPC), C/ Jordi Girona 1-3, Building D2, 08034 Barcelona, Catalonia, Spain.
[4] Department of Chemical Engineering. Universitat Autònoma de Barcelona (UAB).
* e-mail address: jordi.oliver@uab.cat, Tel. (+34) 935 813 760 / Fax. (+34) 935 813 331

Keywords: civil engineering; ecodesign; LCA; public space; industrial ecology; sustainable cities

1. Introduction

The Kyoto protocol, signed by 160 countries, pledges greenhouse gas (GHG) emissions reductions of at least 5% relative to 1990 levels [1]. Besides the global concern and action to mitigate GHG emissions, national-level policies are increasingly being supplemented with city-scale actions to mitigate climate change [2].

Marshall [3] makes us notice that although much attention on mitigating climate change has focused on alternative fuels, energy consumption in vehicles, and electricity generation, better urban design represents an important yet undervalued opportunity.

The built environment is responsible for huge amounts of pollution and waste generation [4] at millions of different locations worldwide. And one of the major construction materials is concrete.

1.1. Cities, neighbourhoods and public space

Concerning the scale of work, much research on urban design has focused on the need for more sustainable design at the city scale, but as Engel-Yan et al. [5] suggest, recently some of this focus has shifted towards the design of sustainable neighbourhoods. Additionally, this scale of work allows extrapolating results to the city scale.

The incorporation of sustainability principles in neighbourhood design is important because many of the problems encountered at the macro-city scale are in fact cumulative consequences of poor planning at the micro-neighbourhood level. In addition, most of these decisions are well within the reach of local governments and leaders and can reduce long-term carbon emissions [3].

In any given urban fabric we can distinguish among two types of subsystems, buildings (including private areas) and public space. Within the public space of cities, concrete sidewalks play an important role in terms of surface and also material use. For example, in the case of Barcelona (Catalonia, Spain), a compact and densely populated city, concrete sidewalks account for 97% of the total sidewalk area, which in turn accounts for more than 45% of the total paved public area. In all likelihood, these statistics could be similar in other cities.

In addition, the public space of cities is an exceptional location for implementing ecostrategies, since the potential for direct environmental benefits is enormous and at the same time provides close example of urban environmental management to citizens.

2. Justification and hypothesis

Using own and recent data provides strength to the results because the environmental assessment literature on concrete is limited and data provided may vary significantly from one source the next, depending on assumptions about system boundaries, fuel types, concrete mixes, and technological differences [6].

The initial hypothesis is that the GHG emissions from the life cycle of concrete sidewalks could be fast and significantly reduced if their structure were not over-dimensioned for resisting exceptional (or inexistent) uses but adapted to the real ones. Furthermore, the environmentally optimal scenario would be that where city planners could adapt the street uses in order to maximize the use of the sidewalks with less contribution to GHG emissions, while assuring the fulfilment of their functions.

This paper estimates the potential saving of GHG emissions that could be achieved in an urban scenario adjusting the sidewalk characteristics to the functional requirements based on the results of the Life Cycle Assessment (LCA) of concrete sidewalks presented by Oliver-Solà et al. [7]. The quantitative environmental data is used here to assess an Eco-Design process at an urban scale, analyzing how different sidewalk scenarios in the same urban fabric affect the results.

3. Materials and methods

Methodologically this study couples environmental quantification tools like LCA with urban planning strategies. The results for the LCA are displayed on a territorial scale using the carbon footprint, and used as environmental information for the processes of urban Eco-Design. Therefore it can be understood as an Eco-Design process at a neighbourhood scale.

LCA. The LCA is a useful and practical tool for guiding planning processes with environmental criteria and it facilitates our understanding of environmental impact on urban infrastructures. In [6] LCA was used to evaluate the global environmental impact of different sections of concrete sidewalks. Although the inventory results characterized using the CML 2 Baseline 2000 [8] indices provided information for various impact categories [6], this paper only focuses on Global Warming Potential (GWP, kg CO_2-equivalent). However, problem shifting is not critical since all impact categories follow a similar pattern for the different scenarios.

Carbon footprint. The carbon footprint, as a component of the ecological footprint, is defined as the land area required today to absorb the amount of GHG released from burning fossil fuels [9]. In most case studies the estimated carbon footprint accounts for half of the total calculated ecological footprint and contributes significantly to ecological deficits [10]. The world average carbon sequestration rate of 95 g C/m^2/year [11] has been used for calculating the carbon footprint.

Eco-Design. The Eco-Design methodology is based on identifying environmental aspects connected with the product life cycle and includes these aspects in the design process at the early stage of product development. Environmental aspects are taken into account on the same level as other essential aspects such as function, safety, ergonomics, endurance, quality and costs.

Urban citizens need proper spaces to move and pass-by in a safe and comfortable manner, and sidewalks provide the appropriate segregation from motorized traffic as well as a more or less flat and regular surface to facilitate pedestrian traffic. There are many different types of sidewalks, made of different materials and with diverse structural sections, to meet these functional characteristics.

Oliver-Solà et al. [6] analyzed several types of widely used concrete sidewalks using the methodology of LCA, and considering the main sidewalk construction/deconstruction stages: raw material extraction, material production/processing, soil compaction, sidewalk installation, sidewalk maintenance/removal and materials transportation (raw materials and components and to final disposal). End-of-life treatment of the infrastructure was not accounted.

The results of part of this analysis are now used as descriptive data for the sidewalks (table 1) that have the following composition characteristics:

Interlocking blocks. On top of the compacted subgrade, a 3-cm layer of sand is used as a base for the concrete blocks, which typically have a compressive strength of 30 MPa. Fine aggregate is poured into the joints and the blocks are compacted with a plate compactor to fit them together. The interlocking blocks considered measure 20 cm x 10 cm x 6 cm, and their composition is usually completely homogeneous.

Slabs. A concrete layer with a thickness of 10 cm or 15 cm with a typical compressive strength of 20-25 MPa is cast on top of the compacted soil (subgrade). The concrete is poured from the mixer truck and spread manually. Generally 15 cm layer is used in parking garage entrances to ensure appropriate structural performance.

On top of the concrete there is a 2-cm layer of dry mortar, on which the concrete slabs are laid, tapped down with a mallet and finished with a grout that seeps through the slab joints into the mortar. The slabs typically measure 20 cm x 20 cm x 4 cm. They have a double-layer structure; the upper layer has a higher compressive strength (approximately 30 MPa) and better finishing.

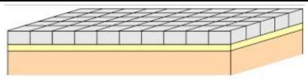
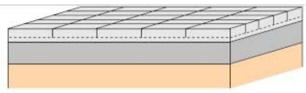
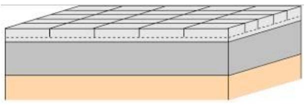
Curbs are not included in the analysis because they are assumed to be the same for all four combinations of sidewalk functions described below and are frequently outside the maintenance area, i.e. they are not affected by trenching.

Besides technical and environmental data, table 1 gives information about four functional units applicable to sidewalk pavements. The functional unit provides a benchmark for inputs and outputs [12]. In this case, the functional unit is one square meter of sidewalk, including all pavement layers extending from the compacted soil (subgrade) to the surface (top layer), over a timeframe of 45 years.

In urban contexts sidewalks may fulfil more than one function. Four combinations of functions have been defined in order to determine which sidewalk type is environmentally optimal for each situation:

- FU_1: Pedestrian traffic only.
- FU_2: Underground services + pedestrian traffic.
- FU_3: Motorized traffic + pedestrian traffic.
- FU_4: Motorized traffic + underground services + pedestrian traffic.

Table 1: Structural section of the analyzed systems, GHG emissions per square meter, and technically suitable sidewalks according to each function.

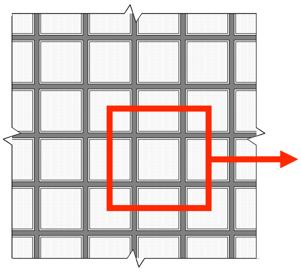
Systems	Acronym	Layout for 1m^2 of sidewalk	kg CO_2-eq./m^2	FU_1	FU_2	FU_3	FU_4
Blocks, 6cm; Sand bed, 3cm; Subgrade	B		19.7	✓	✓		
Slabs, 4cm; Mortar, 2cm; Concrete, 10cm; Subgrade	S10		57.9	✓	✓		
Slabs, 4cm; Mortar, 2cm; Concrete, 15cm; Subgrade	S15		74.3	✓	✓	✓	✓

Source: Adapted from Oliver-Solà et al. [6].

4. Urban fabric selected for the case study

Many different urban fabrics can be found in different cities or even in different districts of the same city; however for calculation purposes a regular grid with blocks of 100 meters (figure 1) has been used as a theoretical reference. All sidewalks and roads are 4 and 12 meters width respectively.

Legend	Use	Surface (m^2)
⁘	Residential	40,000
☐	Sidewalk	6,656
▩	Street	10,944



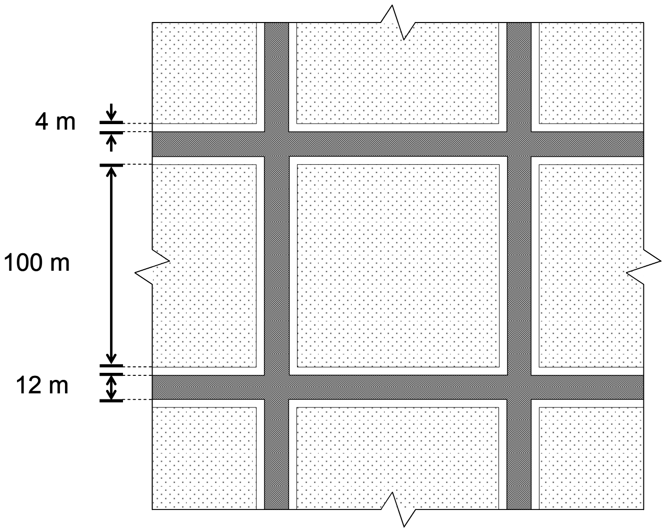


Figure 1: Urban grid studied in this paper.

In the analyzed urban grid the sidewalk surface represents the 11.6% of the total urban surface, and nearly the 38% of the public space.

Concerning the residential uses, they occupy about 70% of the total urban surface. What means that the grid analysed in this paper is representative for an urban fabric with the least surface of public space, both in absolute terms and relative per square meter of floor area. Therefore, the environmental benefits that can be achieved by optimizing the sidewalk structural section are quantified in a restrictive fabric.

5. Results. GHG savings in neighbourhoods through the optimization of concrete sidewalks

According to the types of sidewalks that are currently installed and the backpack of GHG emissions associated to each of them (table 1), the contribution to the global warming potential originated in the public space of any given urban fabric can be quantified.

This section assesses and compares the GHG emissions associated to three scenarios (table 2). In all the scenarios the buildings fulfil the same function, and one garage entrance is allocated every stretch of 20 meters of sidewalk. The analyzed scenarios are as follows:

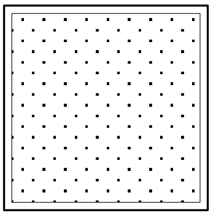
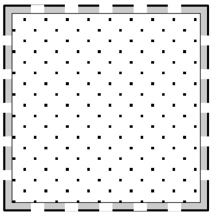
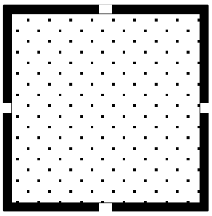
a) **“One size fits all”.** This scenario consists of a generalized application of the S15 structural section which has a high structural resistance thanks to the thicker concrete layer. In addition, when the underground networks have to be repaired or replaced by trenching, the pavement must be reconstructed; this process leaves “scars” that in this scenario can be concealed with new slabs.

b) **Refurbishment (Maintaining the same aesthetic appearance).** This scenario maintains the sidewalks’ aesthetic appearance but optimizes the sidewalk typology to the existing functions. All the sidewalk area is paved with slabs but the pavement is reinforced only in these sections that require such reinforcement, i.e. garage entrances.

c) **Eco-Design.** This scenario implies changes in the urban planning that restrict the number of garage entrances allowed in each street section. This scenario, which could be applied in new neighbourhoods, maximizes the use of interlocking block sidewalks without changing the urban function, neither the uses in the buildings, although it requires a common garage entrance for the whole street section. The goal is to optimize the relationship between public and private spaces, minimizing the environmental impact.

Table 2 shows the emissions of CO_2 equivalent from the life-cycle of sidewalks, both in absolute values per block and per square meter of neighbourhood. This data is used in the last row of table 2 to calculate the carbon footprint associated to the life-cycle GHG emissions of one square meter of concrete sidewalks. Data about Carbon footprint has been given in relative terms (dimensionless) and on an annual basis.

Table 2: Sidewalk scenarios, suitable uses, surface for the whole grid, and associated GHG emissions and Carbon footprint per m^2 of urban area.

	"One size fits all"	Refurbishment	Eco-Design
Pedestrian traffic	✓	✓	✓
Motorized traffic	✓	Restricted to garage entrances	Restricted to garage entrances
Underground networks	✓	✓	✓
Diagram for one block *Sidewalk types* S15 S10 B			
tones CO_2-eq. sidewalks / block	123.6	102.9	37.1
kg CO_2-eq. sidewalks / m^2 urban	8.6	7.1	2.6
m^2 carbon footprint sidewalks / m^2 urban / year	0.55	0.46	0.16

Note: Garage entrances are considered to be 5 meters width.

Results in table 2, reflect that slight and feasible changes in the sidewalk configuration, can lead up to a 70% saving in GHG emissions from one scenario to the next. In absolute values, the potential GHG saving per block in the analyzed scenario is of 86.5 tones of CO_2 equivalent.

As shown in table 2, intermediate solutions are also feasible with the subsequent more limited reductions of GHG emissions (about 16.8% reduction). Moreover, ecostrategies in the public space give room for a gradual application depending on the technical viability or political will.

Concerning the Carbon footprint associated to concrete sidewalks in the "one size fits all" scenario, it is equivalent to more than half of the surface of any given neighbourhood development.

6. Conclusions

The role of optimized infrastructures, highlighted in this paper, reinforces the importance of an adequate planning of infrastructures in the public space of cities for reducing carbon emissions. Efforts at all levels and fields will be needed, and among them urban planning stands out.

Some of the most important reasons for this are:

- The high potential for CO_2 emission reduction that public infrastructures, like concrete sidewalks, have.

- They are publicly managed, meaning that their improvement on a city scale depends on one single actor, which theoretically is more engaged with carbon reduction practices.
- Environmental improvements in the public space of cities provide an example to citizens. This facilitates the communication and comprehension of environmental policies.

The results presented in this paper are especially relevant because reveal that the Eco-Design of infrastructures in the public space of cities can lead to an effective reduction of GHG emissions. The environmental data provided by environmental quantification tools like LCA coupled with urban planning has proved to be useful for guiding this process. Furthermore, the case of sidewalks is especially remarkable since they represent approximately 40% of the public space in a city.

In analogy with the processes of Eco-Design of products, the urban planning process using environmental data in the decision making process becomes a process of Eco-Design at a broader scale.

The results obtained from the carbon-oriented optimization of concrete sidewalks show that the GHG emissions reduction associated with the optimization of concrete sidewalks to the pedestrian uses has a high potential depending on the degree of change introduced. The reduction can be of 16.8% for the “refurbishment” scenario, of 70% for the “redesign” scenario.

References

[1] UNFCCC, Kyoto Protocol. Ed. United Nations Framework Convention on Climate Change, 2006.

[2] Ramaswami A, Hillman T, Janson B, Reiner M, Thomas G. A demand-centered, hybrid life-cycle methodology for city-scale greenhouse gas inventories. Environmental Science & Technology 2008, 42, (17), 6455-6461.

[3] Marshall JD. Energy-efficient urban form. Environmental Science & Technology 2008, 42, (9), 3133-3137.

[4] Hendrickson C, Horvath A. Resource Use and Environmental Emissions of U.S. Construction Sectors. Journal of Construction Engineering and Management 2000, 126, (1), 38-44.

[5] Engel-Yan J, Kennedy C, Saiz S, Pressnail K. Toward sustainable neighbourhoods: the need to consider infrastructure interactions. Canadian Journal of Civil Engineering 2005, 32, (1), 45-57.

[6] Horvath A. Construction materials and the environment. Annual Review of Environment and Resources 2004, 29, 181-204.

[7] Oliver-Solà J, Josa A, Rieradevall J, Gabarrell X. Environmental optimization of concrete sidewalks in urban areas. International Journal of Life Cycle Assessment 2009, 14(4): 302-312.

[8] Guinée JB (final editor). Life cycle assessment; An operational guide to the ISO standards; Parts 1 and 2. Den Haag and Leiden, The Netherlands, 2001.

[9] Wackernagel M, Rees WE. Our ecological footprint: reducing human impact on the earth. . New Society Publishers: Gabriola Island, BC, 1996; Vol. 9.

[10] van den Bergh J, Verbruggen H. Spatial sustainability, trade and indicators: an evaluation of the 'ecological footprint'. Ecological Economics 1999, 29, (1), 61-72.

[11] Wackernagel M, Monfreda C. Ecological Footprints and Energy. In Cleveland C.J. (Ed.) Encyclopedia of Energy, 2004, Elsevier, New York, 1-11.

[12] ISO—International Organization of Standardization, 14040 Life cycle assessment — Principles and framework. Geneva, Switzerland, 2006.