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The GWP-Chart: An environmental tool for guiding urban planning processes. Application to concrete sidewalks

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ABSTRACT

The systematized study of urban morphology has led to the development of integrated tools based on the knowledge of the relation between physical density and urban form. These tools do help planners and decision makers; however, environmental data is rarely included in them.

This paper presents the GWP-Chart, a method that combines urban planning tools with environmental data, obtained through the use of the life cycle assessment (LCA) results. In order to explain its use, three urban fabrics have been selected. According to their morphology and their ground space index (GSI) and public space ratio (PSR) values, the contribution of the sidewalk subsystem to the global impact per square meter of urban development can be quantified and communicated.

The GWP-Chart is applicable to all types of urban fabrics and scales (street or square, island, fabric or district), as well as adaptable to any urban infrastructure or subsystem and can be extended to other environmental impacts. Its advantages lie in its accurateness, adaptability and ease of interpretation.

Introduction

The Kyoto protocol, signed by 160 countries, pledges to reduce greenhouse gas (GHG) emissions by at least 5% in relation to 1990 levels (UNFCCC, 1998). Given the global concern and action to mitigate GHG emissions, national-level policies are increasingly being supplemented with city-scale actions (Ramaswami, Hillman, Janson, Reiner, & Thomas, 2008).

By signing the *Covenant of Mayors* in February 2009, more than 350 cities across Europe committed to go beyond the EU's energy objective of reducing CO_2 emissions by 20% by 2020. With this initiative of the European Commission in partnership with the Committee of Regions, the representatives of over 60 million citizens will work together to achieve the common goal of reducing GHG emissions and using energy more wisely (Convenant of Mayors, 2010). Until now, local strategies for reducing GHG have focused on reducing direct energy consumption. However, further actions should also include the management of urban fabrics and infrastructures in order to achieve greater reductions of GHG emissions.

To complicate the problem further, old cities are expanding (in some cases dramatically) and new ones are emerging worldwide. This unprecedented urban growth will lead to a significant but still poorly analyzed impact on the Earth's environment (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007; Kennedy et al., 2009).

The growth and urbanization of the global human population over the past 300 years has resulted in the construction of cities of unprecedented size and form (Decker, Elliott, Smith, Blake, & Rowland, 2000). Currently, urban population is expanding at a global level, reaching figures of 50%. However, these rates vary from 80% in America to 70% both in Europe and Oceania. By 2050, it is expected that the global share of urban population will reach 70% (UN, 2008).

Despite occupying only 2.7% of the world's surface area (United Nations, 2007), the world's cities are responsible for 75% of the world's energy consumption, including both direct and indirect energy contained in key urban materials such as food, fuel, concrete, water supply, etc., and 80% of GHG emissions (Ash, Jasny, Roberts, Stone, & Sugden, 2008). Therefore, managing urbanization is one of the most urgent practical challenges of sustainability. It is essential to encourage more favorable trajectories of urbanization (Clark,

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2007), taking into consideration the impact of cities on the rest of the globe and the sustainability of life in the cities themselves (Bugliarello, 2006).

Marshall (2008) highlights that although much of the attempt to mitigate climate change focuses on alternative fuels, energy consumption of vehicles, and electricity generation, improved urban design is an important yet undervalued opportunity.

The built environment is responsible for huge amounts of pollution and waste generation (Hendrickson & Horvath, 2000) in millions of different locations worldwide. Therefore, in achieving sustainable development, the building industry is a key player (De Meester, Dewulf, Verbeke, Janssens, & Van Langenhove, 2009). Within this framework, the International Organization for Standardization (ISO) and the European Committee for Standardization are currently developing standards to analyze and certify the environmental impact of buildings and infrastructures, through ISO/TC59/SC17 and CEN/TC 350 respectively.

Although planning activities at the municipal level can incorporate the greenhouse effect in their models (Schmidt Dubeux & Lèbre La Rovere, 2007), planners lack the needed tools to quantify and communicate some of the environmental impacts related to infrastructures in different urban fabrics. These tools would be of great use in supporting decision-making in the urban planning process, especially if we take into account the fact that the planning process generally takes place in a complex institutional environment with a large number of public and private actors (technicians, architects, engineers, politicians, builders, real estate agents, citizens, NGOs), each of them with their own interests and responsibilities (Schuetze et al., 2008).

Furthermore, with the rising interest and demand from policy makers to achieve a sustainable society, the need for environmentally related information is increasing (Forsberg & von Malmborg, 2004).

Urban planning tools and the integration of environmental data

The study of urban morphology and its associated urban parameters is an old but still challenging and complex discipline. In recent years, Berghauser Pont and Haupt (2004, 2005, 2007) have developed an integrated tool called Spacemate (Fig. 1), based on the knowledge of the relation between physical density and urban form.

Berghauser Pont and Haupt (2007) reported that density is not only determined by the number of square meters of built floor area in relation to the land area, but factors such as compactness, building height and the amount of non-built space also play an important role in defining urban fabrics.

The four variables defined by Berghauser Pont and Haupt (2005, 2007) and shown in Fig. 1 are:

- Intensity, defined by the floor space index (FSI) [gross floor area/plan area]: reflects the building intensity independently of the programmatic composition, and indicates the space of built floor (surface constructed in buildings) in relation to the land area.
- Compactness, defined by the ground space index (GSI) [built area/plan area]: it is the percentage of the land area covered by buildings.
- Pressure on non-built space, defined by the open space ratio (OSR) [(plan area-built area)/gross floor area]: it is the amount of non-built space at ground level per square meter of floor area. If more floor area is developed in an area with the same footprint, the OSR decreases and the number of people who will use the non-built space increases.
- Building height, defined by the layers (L) [gross floor area/built area].

According to the authors, if density is defined not just as intensity (FSI), but as a combination of intensity, compactness (GSI), pressure on non-built space (OSR) and height (L), it can be used to differentiate between urban forms in a more efficient way (Fig. 1).

According to some of these parameters, and based on the environmental data generated by assessing urban infrastructures (Saiz, Kennedy, Bass, & Pressnail, 2006; Oliver-Solà, Gabarrell, & Rieradevall, 2009a, 2009b; Oliver-Solà, Josa, Rieradevall, & Gabarrell, 2009c), it seems possible to generate tools that communicate the environmental results to planners. The key aim is to provide high quality, life cycle-based, environmental information to planners

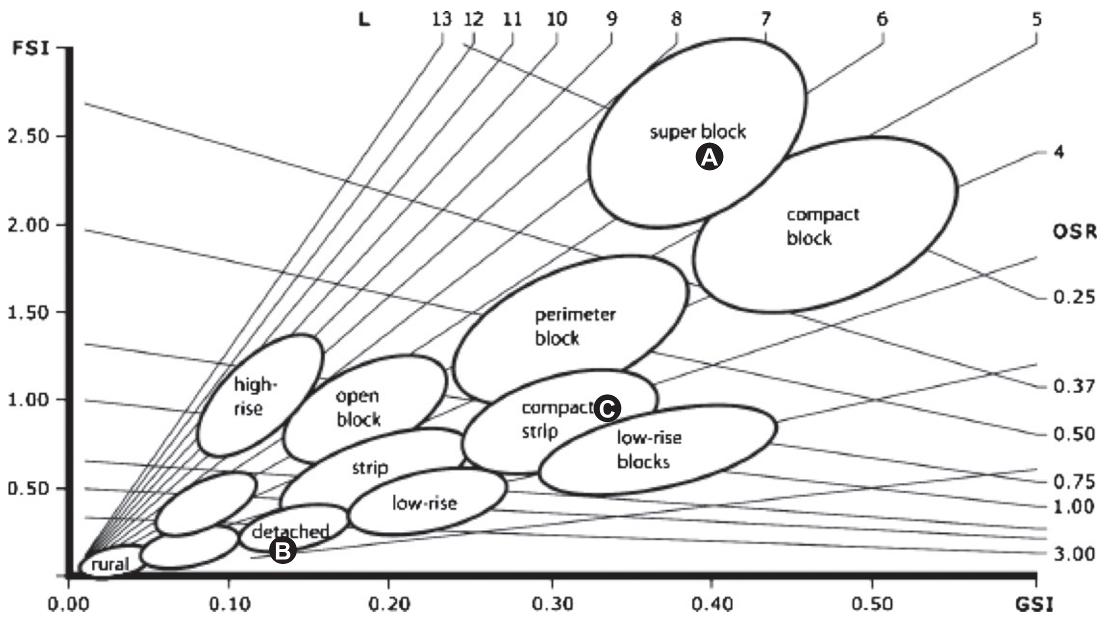


Fig. 1. Spacemate diagram. *Note*: The figure includes references to three urban fabrics (A–C) that will be used later in the analysis in Table 2.

through a tool that is both useful and understandable to those responsible for new urban development or refurbishing. In other words, there is a need for high quality environmental information to be integrated into the existing planning tools.

As Ortiz, Bonnet, Bruno, and Castells (2009) argue, applying Life Cycle Management (LCM) to the built environment life cycle is very important for reducing environmental loads and therefore for achieving sustainable development.

Justification

It seems increasingly more likely that the environmental and energy concerns that nowadays focus mainly on buildings will soon be transferred to neighborhood planning. Indeed, the US Green Building Council (USGBC) has recently developed the LEED certificate for Neighborhood Development (USGBC, 2010) which aims to integrate the principles of smart growth, urbanism and green building into the first North American system of neighborhood design. Given the global renown of LEED certificates, this new commitment toward neighborhood design may mark an inflection point in planners' attitudes and needs for the development of additional environmental tools. In focusing on neighborhood designs, planners, architects and policy makers will need to measure, in a simple way, the environmental impact associated with urban subsystems, by complementing the existing planning tools with additional environmental data.

As indicated above, there is a lack of environmental tools to guide urban planners through design/redesign processes. However, urban planners already work with some physical parameters that are valuable for an environmental analysis and which at the same time could facilitate decision-making processes. Using this as a starting point, this paper develops a case for concrete sidewalks, which have been selected for three reasons: they constitute a significant proportion of the urban public space, they exist in most urban fabrics worldwide, and the authors have previous experience in the environmental analysis of this urban subsystem (Oliver-Solà et al., 2009c).

Objectives

The main objective of this paper is to propose a generic useful tool to guide planning processes from an environmental perspective. This can be divided into three sub-objectives:

(1) Generate a new environmental tool for urban planners, using elements of their own toolbox in order to facilitate their comprehension and application.
(2) To test and verify the proposed tool to represent GHG emissions stemming from concrete sidewalks in the public space of cities.
(3) To compare the GHG emissions from concrete sidewalks for different urban fabrics and construction solutions. This could be also reproduced for other impact categories calculated by life cycle assessment (LCA).

Materials

In order to develop a new tool for integrating environmental aspects to urban planning processes, and specifically for indicating the contribution of concrete sidewalks to the global warming potential (GWP) of different urban fabrics, three aspects have to be carefully analyzed:

- GWP per square meter of different representative concrete sidewalks, measured following LCA procedures.
- Urban morphology parameters. Ground space index (GSI) and public space ratio (PSR) are the key parameters for analyzing the sidewalk subsystem.
- Definition of urban fabrics where the tool applies.

GHG emissions from concrete sidewalks

Oliver-Solà et al. (2009c) analyzed several types of widely used concrete sidewalks using the LCA methodology, while considering the main sidewalk construction/deconstruction stages. Similarly, in this paper, the results for GWP account for emissions arising during the life cycle of concrete sidewalks. The functional unit applied was 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. Some of the results obtained in the aforementioned paper, corresponding to part of the concrete sidewalks analyzed (Table 1), will serve as the basis for the GWP data that will be included in the tool. Inventory data was obtained from an average of concrete production in Europe. Therefore, the results expressed in the tool (Fig. 2) are suitable for a European context.

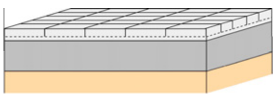
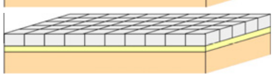
In the present case, the environmental impact is limited to GWP, but other cases could also be developed for other impact categories (acidification, eutrophication, abiotic depletion, etc.). However, since cement content is the key factor in determining the environmental impact, the results obtained for the GWP impact category in concrete sidewalks followed the same trend as the other impact categories that were originally analyzed (Oliver-Solà et al., 2009c). Given the importance and extensive usage of concrete within cities, this study helps advance our knowledge regarding the larger scale contribution of this material to global warming.

Urban morphology parameters

GSI was defined by Berghauser Pont and Haupt (2007) as the percentage of the land area covered by buildings (excluding other urbanized areas). However, the totality of the urban fabric includes open surfaces (i.e., areas without buildings). These areas include public (pedestrian areas, roads and green areas) and private spaces (not including residential spaces, such as patios).

Within the public space, different uses can be defined. Given the focus of this paper, PSR is defined as the ratio between the sidewalk surface and the total non-urbanized surface

Table 1
Structural section of the analyzed systems, GHG emissions per square meter.

Systems	Acronym	Layout for 1 m^2 of sidewalk	kg CO_2 eq./m^2 Oliver-Solà et al. (2009c)
Slabs, 4 cm; mortar, 2 cm; concrete, 15 cm; subgrade	1		74.3
Blocks, 6 cm; sand bed, 3 cm; subgrade	2		19.7

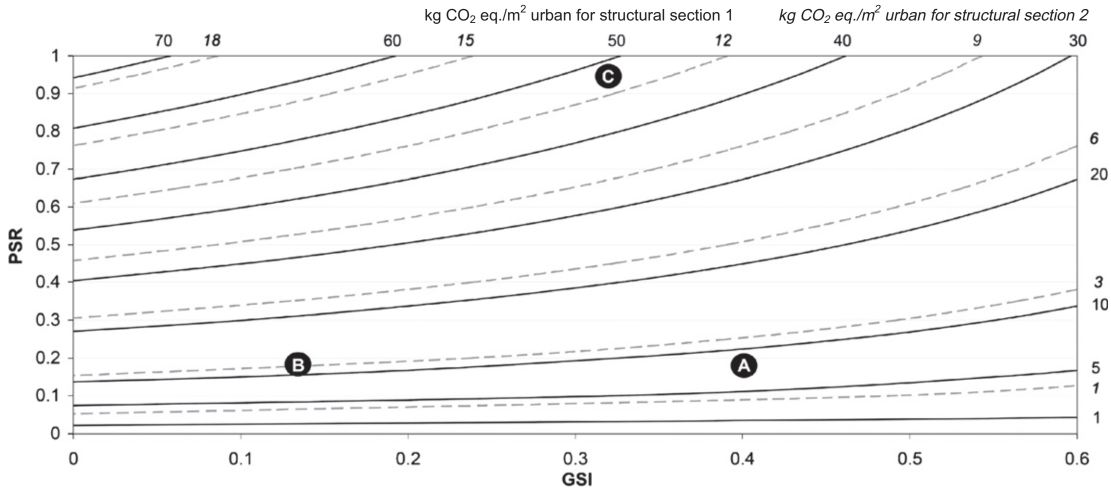


Fig. 2. GWP-Chart for structural sections 1 and 2 (Table 1) of concrete sidewalks.

$$\mathrm{PSR} = \frac{\text{sidewalk surface } (\mathrm{m}^2)}{\sum \text{surfaces without buildings } (\mathrm{m}^2)}. \tag{1}$$

According to the above equation, PSR values of close to 1 represent pedestrian neighborhoods, with most of the public space devoted to public pedestrian areas. On the contrary, values close to 0 are associated with urban fabrics designed, almost exclusively, for motorized traffic use or with the public space occupied by green areas.

Although, according to our own estimates, the majority of urban areas would have PSR values of between 0.15 and 0.4, the scale in Fig. 2 has been left at 0–1. This will allow the results to be used at different scales (street or square, block or district) where PSR may have a wider range.

Urban scenarios

While there are a number of different possibilities for constructing various urban surfaces, for explanatory purposes, we focus on three regular grids in this paper. The widths of sidewalks and roads are different in each of these three urban fabrics: 4 m and 12 m for A; 1.5 m and 4.5 m for B; and 10 m and 0 m for C, respectively. These values are estimates based on a criterion of proportionality between the different urban subsystems.

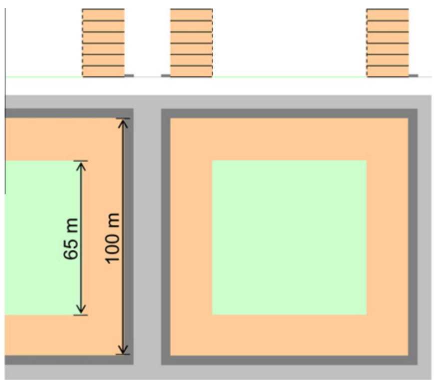
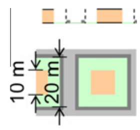
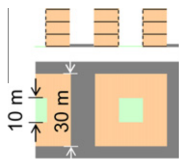
Table 2 presents the plan and surfaces of the different uses for one block in the three urban fabrics and their associated GSI and PSR values. As has been shown on the Spacemate (Fig. 1), urban fabrics A–C represent super blocks, detached or low rise blocks and compact strip (pedestrian) fabrics, respectively.

Due to their surface differences, the GSI values are similar for A and C, and much lower for B. On the contrary, the PSR values for A and B are similar and much lower than the value for C.

Methods

The GWP-Chart (or CO_2 e-graph) can be defined as a tool for representing and communicating the GWP (and also adapted to be used for other global or regional impact categories) of urban

Table 2
Analyzed urban fabrics and their associated parameters.

Urban fabric	A	B	C
Vertical profile and horizontal layout			
Road (m^2)	2736	227	0
Sidewalk (m^2)	1664	129	1600
Residential first floor (m^2)	5775	100	800
Light well or garden (m^2)	4225	300	100
GSI	0.40	0.13	0.32
PSR	0.19	0.20	0.94

Road [ ], Sidewalk [ ], Built [ ], Light well/garden [ ] infrastructures per square meter of urbanized area in any urban fabric.

The tool was developed as an assessment method for planners and, although in this paper it is applied to concrete sidewalks, aims to be applicable to any other urban subsystem and situation when adapted appropriately. The goal is not only to give data (which can be calculated), but to provide information to communicate and understand trends, departing from basic planning information such as GSI and PSR. These variables are easy to obtain and are already used to analyze other aspects of a project. The GWP-Chart uses these variables to provide environmental information and trends to planners.

The GWP-Chart is a two dimensional graph with the planning variables on the *X* and *Y* axes. Each combination of *X* and *Y* defines a different environmental load from the analyzed subsystem. An example of this calculation is represented in Eq. (2) for scenario A, using the constructive solution number 1.

$$\text{kg } CO_2 \text{ eq.}/m^2 \text{ of sidewalk} \cdot (1\text{-GSI}) \cdot \text{PSR} = \text{kg } CO_2 \text{ eq.}/m^2 \text{ urban} \quad (2)$$

$$74.3 \text{ kg } CO_2 \text{ eq.}/m^2 \text{ of sidewalk} \cdot 0.60 \cdot 0.19 = 8.5 \text{ kg } CO_2 \text{ eq.}/m^2 \text{ urban.}$$

The units on the diagram correspond to kg CO_2 per urban square meter. This means that the GWP-Chart determines the average contribution of the subsystem analyzed to every urban square meter, regardless of its use.

In a way, the GWP-Chart could be understood as a tool for showing carbon footprint results in an understandable way for architects or urban planners, with the urban morphology data as the only data entry. At the same time, it is a tool applicable to other impact categories and urban subsystems, which is particularly useful for understanding and communicating trends.

Results and discussion

This section applies the GWP-Chart to the scenarios and construction solutions presented in 'Materials' section. Fig. 2 shows the GHG emissions stemming from the structural sections 1 and 2, which are the construction solutions that emit most and least GHG for concrete sidewalks presented by Oliver-Solà et al. (2009c).

The results for the GWP-Chart applied to the concrete sidewalks of the three urban fabrics selected in the materials section are presented in Table 3 and Fig. 2. Here the GWP-Chart is tested under various scenarios, which strengthens the method presented and helps to interpret the results for different GSI and PSR values.

At any given point in the diagram, the difference in GHG values between both isolines can be understood as the potential savings that could be achieved by using the construction solution that causes the least impact (last line on Table 3).

On the diagram (Fig. 2), moving from left to right, the GSI value increases, as does the built area. At the same time, moving from bottom to top implies increasing the ratio of sidewalk surface in the non-built space of any given urban development.

Planners that wish to use the GWP-Chart only have to calculate the PSR and GSI values, place the results on the diagram, and read the kg CO_2 eq./m^2 value of the isoline in the appropriate structural section.

Table 3
Results for the three scenarios under study.

	Scenario		
	A	B	C
Structural section 1 (kg CO_2 eq./m^2 urban)	8.5	12.9	47.5
Structural section 2 (kg CO_2 eq./m^2 urban)	2.2	3.4	12.6
Difference/potential saving (kg CO_2 eq./m^2 urban)	6.2	9.5	34.9

The diagram shows that isolines of GHG emissions from sidewalks per square meter of urban use increase:

(1) when there is an increase in the proportion of pedestrian areas, and/or
(2) when the area with buildings is reduced in favor of public spaces.

With this information, it is possible to estimate the trend of change in GHG emissions (emitted or saved) that is linked to specific decisions both in new developments and in refurbishments of pre-existing urban areas:

- In new developments, it is possible to modify the planning process by first selecting a particular location within the GWP-Chart, and then choosing the most appropriate construction solution that achieves that value. Although the utility of the GWP-Chart as a tool for calculating is limited, the key point is that it helps with understanding the problem and the environmental consequences associated with a planning decision.
- In refurbishments, the location on the GWP-Chart is already pre-established (as in scenarios A–C). Consequently, in this case the tool can only evaluate what would be the consequences of selecting different construction solutions (1 or 2 in the example). Therefore, even in areas where the decision options are more limited, the GWP-Chart can still be useful.

The GWP-Chart proves that different urban morphologies determine the range of environmental impacts produced by their infrastructures. According to Fig. 2 and values in Table 3, scenarios B and C have approximately 35% and 82% higher impact, attributable to sidewalks per square meter of urban space, than scenario A.

The analysis of Fig. 2 shows that urban fabrics with very different GSI, but similar (and low) PSR (like scenarios A and B), still have similar values of emissions per square meter of urban space.

Urban fabrics with a high proportion of sidewalks in their non-built space (like scenario C) are situated on the upper part of the diagram. In these areas, the emission values are higher and the variations of GSI have a greater influence on the results.

The potential of the GWP-Chart is to guide planners, providing information on the environmental trends and repercussions of any given urban configuration. However, this tool needs to be complemented with LCA, in order to create a full assessment of different infrastructures and construction solutions, since the trade-offs between urban infrastructures cannot be fully identified by the GWP-Chart. Without this element, reductions in the GHG emissions for any one area, as estimated by the GWP-Chart, do not necessarily translate to a reduction on a city scale.

Conclusions

The quantitative research on the global environmental impacts of urban infrastructures is still in its early stages. However, due to the environmental relevance of these urban infrastructures and the need to communicate results to planners, new tools have to be developed in order to facilitate the decision-making process. The GWP-Chart aims to be useful in transferring high quality environmental information.

The results obtained show that the GWP-Chart can:

- Be applied to all types of urban fabrics, and also at different urban scales (street or square, block or district).

- ○ Represent values for GHG emissions of different structural solutions; and it is suitable for representing values for other urban subsystems, both in a different diagram or adding the data to the pre-existing one.
- ○ Describe the environmental performance of any urban area, before, during or after a planning process.

Furthermore, the GWP-Chart has different functions such as:

- ○ *Prospection*: In the early stages of urban planning, the preliminary data about basic urban parameters can be placed in the diagram. This will give an approximate idea of what the environmental impact attributable to different subsystems of the new development would be.
- ○ *Evaluation*: The diagram can also be applied to verify the environmental impact associated with an urban subsystem once a development has been finished, or a pre-existing urban area has been analyzed.
- ○ *Comparison*: The diagram is an excellent tool for comparing the environmental impact associated with different urban subsystems in any given urban fabric, as it allows the different urban fabrics to be represented on it.
- ○ *Communication*: The ease of representation and understanding of the diagram makes it a good tool for communicating the environmental results to non experts.

Future research should focus on analyzing other urban subsystems, construction solutions and materials in order to provide the GWP-Chart with a full perspective of the urban environment. At the same time, a more detailed and exhaustive quantification of the GHG emissions from other urban subsystems would allow maps for describing the intensity of GHG emissions from different urban infrastructures to be created.

It should be also considered that the same methodology could be applied to other environmental impact categories, since LCA results for urban infrastructures can generate this data as well.

Finally, it could be effective and useful to develop a simple spreadsheet, which would allow the user to input the type of sidewalk, the urban parameters (GSI, PSI), and then calculate the GWP. Moreover, the user could also update or modify the GHG emissions to reflect properties of other materials (other than concrete). It would also be simple to then include other impact factors (such as acidification, eutrophication or abiotic depletion), and eventually expand the model to include buildings as well. Such a model would be really useful to planners, for whom the GWP-Chart presented in this paper can be considered as a tool for understanding how the environmental impacts change under various scenarios (and not specifically a tool for calculating such impacts).

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