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# Towards a sustainable district: a streamlined Life cycle assessment applied to an Italian urban district

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# Towards a sustainable district: a streamlined Life cycle assessment applied to an Italian urban district

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**Abstract.** The literature shows a lack of environmental indicators able to support the transition from a sustainable to a smart city framework, since the priority area "built environment" is indeed more comprehensively addressed by urban sustainability assessment systems (13%), than by smart city frameworks (4%) [12].

As "smaller cities inside a larger agglomerate" [19], urban districts play a key role in defining effective and innovative paths toward a smarter city, but defining a sustainable urban district is not straightforward, and even less is capturing the induced impacts due to interactions between individual buildings and their surround urban setting [23]. The adoption of a quantitative method for evaluation, such as Life Cycle Assessment (LCA), emerges as an essential step for this purpose [24].

This article explores the application of a streamlined LCA on the urban district main issues (buildings, energy, water and waste), referring to an urban retrofitting intervention of Bolognina neighbourhood.

A set of mitigation strategies developed by an interdisciplinary research group (joining researcher team from the Department of Architecture of the University of Bologna and Institute of Sustainability in Civil Engineering of the RWTH Aachen University) provides the reference framework for the application deepened within the article. This work is a first application of LCA to a case study but it not includes a comprehensive sustainability framework yet, further activities are planned to finalize the analysis, e.g. taking account of social dimension by applying Social Life Cycle Assessment.

## 1. Introduction

Cities Climate Leadership Group (C40) emphasize that despite occupying just 2% of the world's landmass, Cities are responsible for over two-thirds of the energy consumption and account for more than 70% of global $CO_2$ emissions.

As a significant contributor to climate change issues, cities represent a key challenge in curbing greenhouse gas emissions and in taking adaptation and mitigation strategies.

Therefore, the consolidation of the common approach launched by the Paris Agreement, which focuses on transition to climate change, is encouraging cities, regions and businesses to take important steps in this direction, in order to contribute reduce global temperature rise to less than 2 Celsius degrees [1].

In parallel, an interdisciplinary group of academic experts who provided independent insights to COP21 French presidency and negotiation team, underlines that strategies foreseen in the Paris Agreement, on response to greenhouse gas rise, whilst being a laudable first step, requires scientific community to make further interdisciplinary efforts, as those regarding a broader use of Integrated Assessment Models [2].

According to several literature sources, the three interconnecting pillars: economic growth, societal development and natural resource conservation should be the reference to adopt in shifting towards sustainable urban development [3-5].

Life Cycle Sustainability Assessment (LCSA) is the life cycle-based approach built on the ‘triple bottom line’ or 'three-pillar' model of sustainability: environmental (LCA), social (SLCA) and economic (LCC) [6-7].

Since it is an accepted methodology for quantitative assessment of buildings over their whole life cycle, LCA has been increasingly used to assess the environmental impacts of construction products and buildings in the last 25 years, while it is still difficult to apply at urban level.

Despite the application at district level highlights the difficulties in shifting LCA to a wider scale [8], the methodology could provide a robust framework for an effective tool, suitable to assess environmental issues of urban blocks or neighborhoods. Which is a very promising issue within the actual debate on the lack of environmental indicators capable in providing guidance in the transition from a sustainable to a smart city framework.

This study applies a streamlined life cycle assessment to evaluate the mitigation strategies adopted by local authorities to enhance the environmental features of an Italian urban neighbourhood within its path to became a sustainable district.

## 2. Background

### *2.1 Towards a sustainability framework for new district urban concepts integrated in smart cities*

The large variety of smart city definitions converge in European Union's view, under which the aim of the smart city is reducing greenhouse gas emissions in urban areas through the deployment of new intelligent technologies [12]. In fact, a large gap exists between a sustainable city and a smart one.

Recent scientific literature on the assessment of smart city performance suggests that there is a need to further integrating sustainability indicators in existing frameworks, or totally re-defining them. In particular, it recommends that not only output indicators should used that measure the efficiency of smart solutions deployment, but also impact indicators assessing the contributions provided to ultimate goals, such as environmental, economic and social sustainability.

A shift there has been in recent years by city policies striving for smart city targets instead of sustainability goals [9]. However, those two topics are interconnected and smart cities often share several goals with sustainable cities., despite the relation to sustainability targets is often lost within the large variety of definitions that exists of smart city [10]. Hence, there is a need to better understand the relation between smart and sustainable city concepts [11].

Built environment is an important aspect underlying the notions of both smart and sustainable cities. Comparing sustainable and smart city frameworks [12], the priority area "built environment" is more comprehensively addressed by urban sustainability assessment systems (13%), than by smart city frameworks (4%). It further highlights an additional lack of environmental indicators able to provide guidance in implementing the transition from a sustainable to a smart city framework.

However, these studies do not adopt the life cycle approach and can therefore only be assumed as a starting point, since impacts along the life cycle phases may have been neglected, e.g. energy embodied into buildings and infrastructure components to manufacture, ship, maintain and eventually demolish & dispose them [13]. Conversely, adopting a life cycle perspective will help understanding the up and downstream impacts of different technologies and concepts. This will also enable the identification of hotspots along the supply chains, providing a mean by which optimization potentials can be identified, while avoiding trade-offs.

### *2.2 LCA at urban level*

A shift to sustainable districts has become urgent nowadays. This needs having tools to assess and measure the sustainability of Urban District, and especially their Retrofitting process. LCA is considered a valid scientific methodology for the purpose, but it could lead to uncertain outcomes and be highly time consuming, due to its specific nature which strictly relies on accurate and detailed input data. Many studies highlighted the need of removing this obstacle by adopting simpler methods or switching to other approaches (e.g. material flow analysis) [14]. Lotteau et al. [8] provides recommendations and guidance on applying LCA at this scale, based on the review of 21 case studies. In particular, the study suggests two good practice to adopt: a) declaring in detail the key features of the neighbourhood (i.e. number of inhabitants, number of non-resident users, neighbourhood area, total floor area and duration of study), in order to allow a better interpretation of results and data comparison; b) aligning LCA to the data as defined at master planning stage of the neighbourhood development, specifying key factors such as urban morphology, presence of vegetation, choice of materials and their influence on buildings energy consumption.

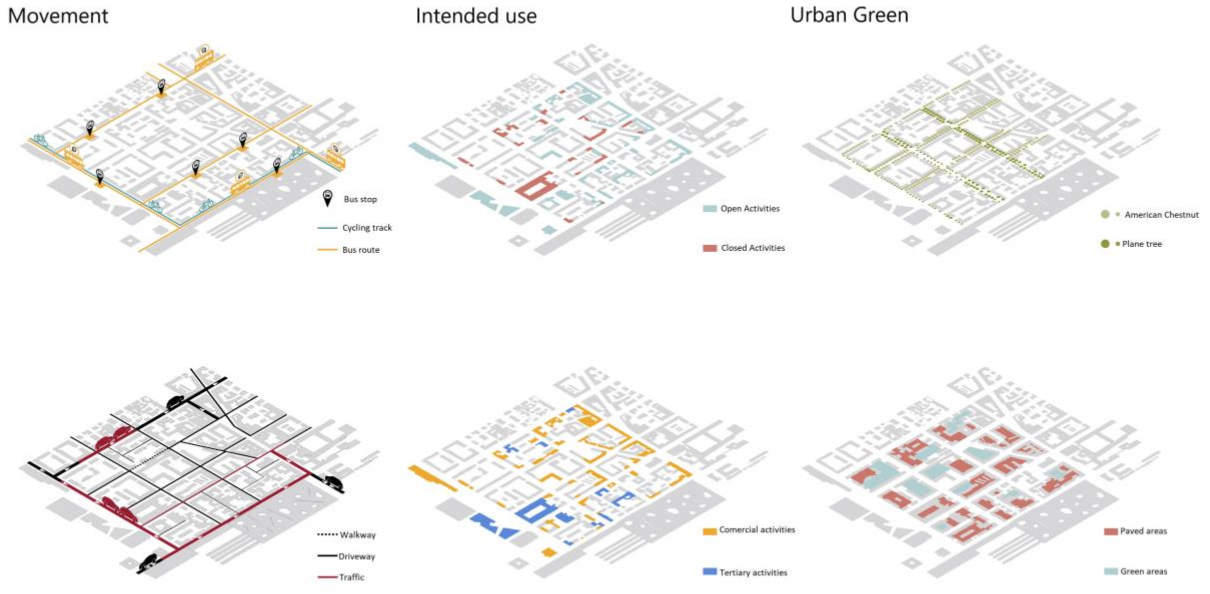

**Figure 1.** Analysis of site at Urban scale (redesigned by authors [17])

## 3. Case study

### *3.1 Bolognina district*

The area under study is the Bolognina Neighbourhood, one of the 6 neighbourhoods which constitute the Italian city of Bologna. Located in the northern part of the city, this neighbourhood came into being as a result of urban expansion to provide residence for the working class at the end of 19th century. It has a strategic location, close to the new stop for high-speed trains, the recent main City Hall building and the new residential area in the former fruit and vegetable market. Situated west of the trade fairground and east of the parallel Adriatica Motorway A14 and Tangenziale Nord Highway, it represents an important pivot between the historical city centre and the surrounding outskirts (Figure 2).

The Urban Plan of 1899 conferred to the area its peculiar chessboard pattern, made up of plots alternating homes, open yards, public services and shops. The most common buildings types are terraced houses aligned along the boundaries of the lots, and standalone often higher buildings in between. Some of the buildings are submitted to conservation plans as they are deemed of testimonial interest by city regulations. However, there is need for actions to address some critical issues, especially those due to the aging of the building stock and socio-economic conditions, as well as to improve the urban quality and to raise environmental and energy-related standards.

### *3.2 Critical issues*

### *3.2.1 Heat island effect*

A simulation was performed using ENVI.met software, in order to better understand the physical and micro-climatic behaviour of the urban area under study as wells as interactions among the elements present therein. This allowed us to identify heat island effect, air flow dynamics and vegetation related benefits. The simulation was carried out on three different levels: a large portion of the built environment including part of both historic city centre and surrounding area; the northern section of Bolognina neighbourhood; a single Bolognina block. This "zoom" sequence has highlighted significant heat island effects especially in no-shade unconstructed paved areas; low relative humidity (rarely higher than 40%); critical wind speeds often affecting zones without physical barriers such as vegetation and/or buildings (Figure 3).

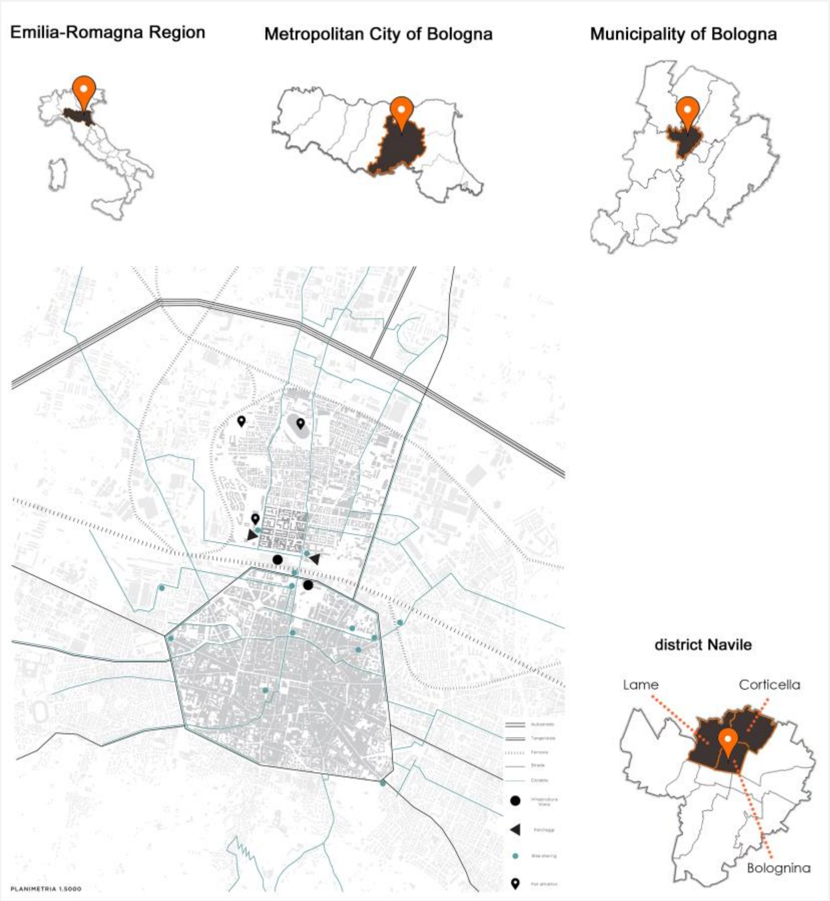

**Figure 2.** Territorial location of Bolognina neighbourhood

### *3.2.2 Open spaces*

A more detailed study was also carried out on unbuilt areas, showing that green zones, parking lots, paths, home entrances (Figure 4) are left in abandoned and degraded situation due to the lack of a hierarchical organization of the common spaces and their ordinary specific use, resulting in an inefficient use of the urban area.

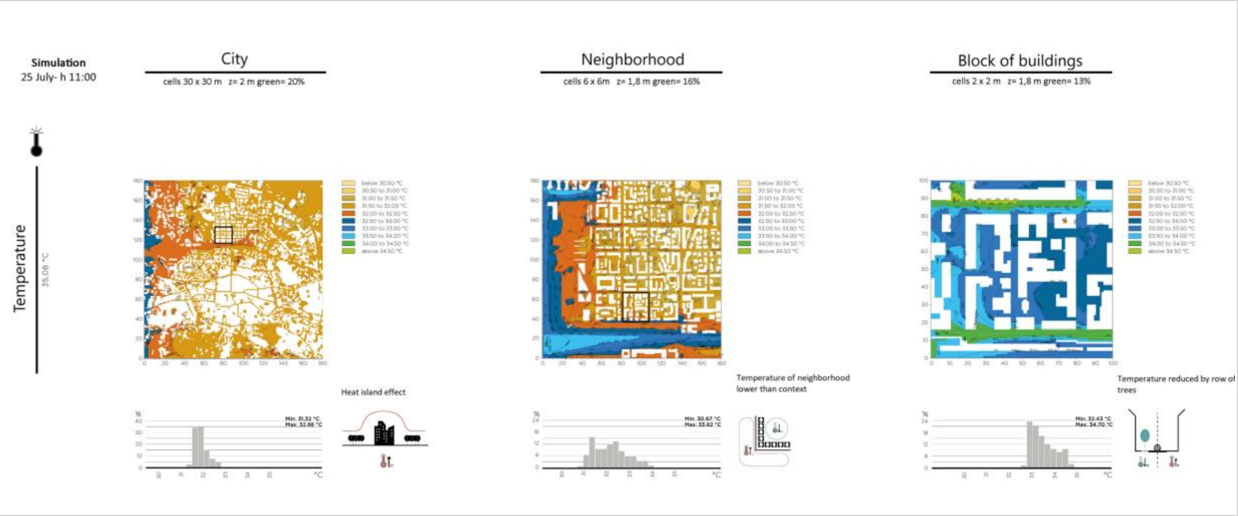

**Figure 3.** Head island effect on Neighbourhood (redesigned by authors [17]

*3.2.3 Buildings*

Residential buildings have inadequate performance levels: 70% of the rooms have lower surface areas compared to existing legal limits, 20% are under-sized by more than 70%. The type of lodgings, which today are mainly made up of 2-3 components, do not meet demands. The indoor comfort levels (exposure to sunlight and ventilation) are at critical levels; energy consumptions are very high (total energy performance Ep values range from 130kWh/$m^2$ corresponding to energy class E, to 230 kWh/$m^2$ corresponding to energy class G), mainly due to heat loss of the building envelopes, in particular windows, and to a high number of heat bridges.

## 4. Methods

*4.1 Mitigation strategy of Bolognina and relevant environmental aspects*

The opportunities and criticalities highlighted in previous analyses have been grouped in 4 categories: city, utilities, insulation and comfort. The strategic interventions were defined taking into consideration their repeatability at a higher scale, which means extending to other neighbouring blocks in order to involve the whole district. These interventions address 8 aspects of the built environment as illustrated in Figure 4.

### *4.1.1 Urban district scale*

The area defined by the courtyards and squares, as highlighted in the analysis in section 3.2.1 occupy a key function in the composition of the neighbourhood and shows serious functional deficiencies. The objective at the urban block scale, is to reorganize and requalify the open spaces in the internal courtyards, with the aim to re-establish a balance between built volume and open areas, reducing as much as possible the transit and parking of vehicles and extending the green surfaces.

### *4.1.2 Building level*

The existing building stock plays a significant role in energy consumption and $CO_2$ emissions, accounting respectively for 40% and 36% of EU related amounts [15].

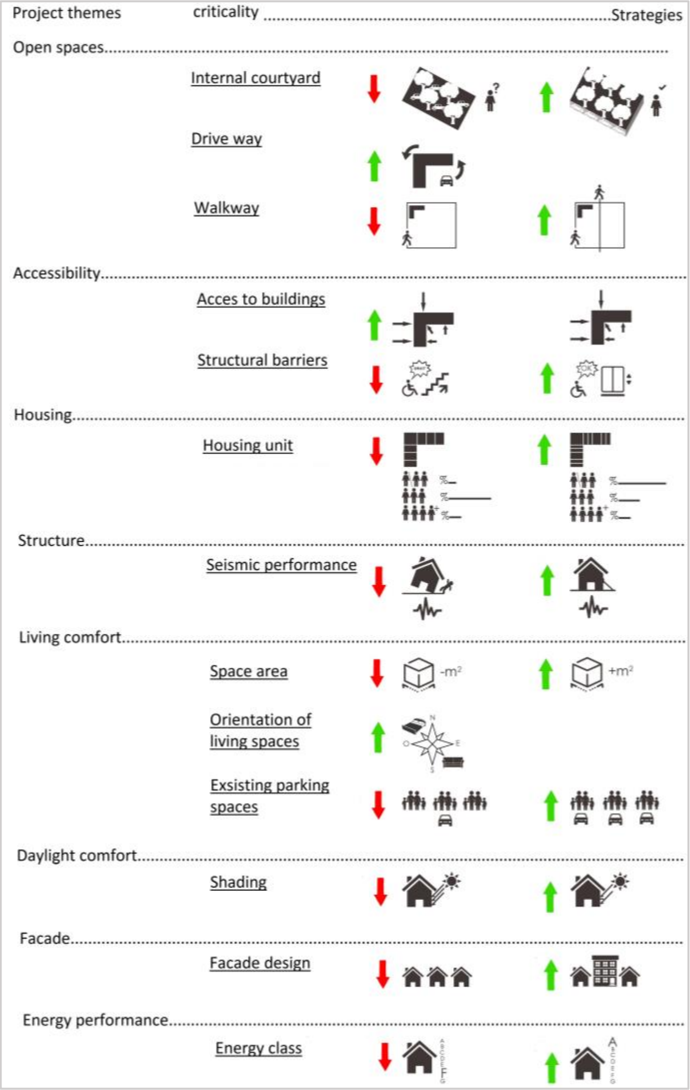

**Figure 4.** Mitigation strategies adopted

This occurs at district level too: there is therefore need to implement energy efficient and low carbon retrofit solutions which must be also affordable and designed for a long lifespan, since buildings are made to last for several decades (60 years, in accordance with the European Framework Level(s) [25].

By adopting pertinent solutions (building envelope insulation, window replacement, energy saving technical installations, etc), energy efficiency labelling could improve from class G (230 kWh/m2 year) to Class A2 (37,2 kWh/m2 year) and from Class F (160 kWh/m2 year) to class A4 (16,96 kWh/m2 year).

### *4.2 LCA of the Italian urban district*

The LCA study was applied on the block bordered to the west by Via Nicoló Dall'Arca, via Fioravanti to east, Via Tibaldi to south and Via Albani to north, which is affected by intense traffic flows also due to daily local market here hosted and the proximity of City Hall.

These roads have uniform three-ways section: driveways are in the middle, two lines of public metered parking are located on both sideways which are lined with trees and sidewalks. Table 1 shows in detail the situation of the block under study.

**Table 1.** Dimensional characteristics related to the block under study

| **Characteristics** | **UM** | | **Value** |
|---|---|---|---|
| Height of the building (average) | m | | 16 |
| Built volume | $m^3$ | | 80,78 |
| Open area | $m^2$ | | 8910 |
| Open/built area ratio | | 0.46 | |
| Green/pavement area ratio | | 0.75 | |
| Lodging area | $m^2$ | | 1648,5 |
| Lodging n. (+/- 5%) | n. | | 190 |
| | $m^2$ | | 10879,9 |
| Green surfaces | $m^2$ | | 3862 |
| Pavement surfaces | $m^2$ | | 5108 |
| Block total area | $m^2$ | | 13036 |
| Built area | $m^2$ | | 4111 |
| Lodging average surface | $m^2$ | | 65 |
| Inhabitant/lodging average index | n. | | 2,5 |

The study firstly aims at exploring the application of a streamlined LCA on an urban retrofitting intervention of Bolognina neighbourhood. For this purpose and focusing on urban district main issues (buildings, energy, water and waste), a set of mitigation strategies has developed by an interdisciplinary research group (joining researchers of the Department of Architecture of the University of Bologna and Institute of Sustainability in Civil Engineering of the RWTH Aachen University).

The additional scope is to respond to some questions emerging in literature about the selection of functional unit suitable to allow effective interpretability of LCA results at neighboured scale, thus the studies comparability.

In order to reduce the number of variables involved and thus simplify the application model, LCA analysis focuses on some mitigation measures only, among those adopted in the retrofit intervention, as well as on two main life stages only, which are those defined in 4.2.2.

### *4.2.1 Functional unit*

LCA standards define the functional unit (FU) as the quantified performance of a product or system that is used as the reference unit for the LCA and for comparability among assertions (ISO 14040-14044:2006). The standard EN 15978 (2011) on LCA calculation methodologies at building level relates the FU to the quantification of product identified functions or performance. For example, FU can be defined at building element level as $1m^2$ of insulation with sufficient thickness to provide a thermal resistance value of 3 $m^2K/W$, while at whole building scale it can be a unit of living area (1 $m^2$).

Given that an urban district - as the neighbourhoods it is composed of - are ecosystems, which characteristics are related to a considerable number of aspects (geographical location, space area, open spaces, building, culture and wealth of local residents to cite a few examples), the definition of a functional unit for these systems is extremely challenging [14].

As a matter of fact, state of the art on LCA studies applied at neighborhood level shows huge differences in FU choice However, we found an interesting reference in Norman et al. [15] and Stephan et al. [16] adopting a per capita FU (m2 of living space/inhabitant) but unfortunately it is cannot be used as a reference for our study, because is not clear how the amount of the open spaces is considered. This assessment is referred to dimensional characteristic of the block of Bolognina urban district, namely 8910 m2 of open area, about 190 housing units with 10879 m2 of living spaces and 475 inhabitants (see Table in Figure 2).

### *4.2.2 Boundaries and Life Cycle stages*

Within the present study, the envisaged mitigation actions related to the built environment have been at first clustered by three main fields: buildings, open spaces and networks. This is in line with the model introduced by Popovici [18] and broadly taken over by the framework developed by Lotteau et al. [8], which allows to identifying the factors acting as major contributors within the LCA of an urban district (Figure 5).

In accordance with the boundaries defined by EN 15804 standard, the stages involved in the analysis are:

i) Product stage (raw materials extraction, manufacturing);
ii) Construction phase (Transport, building and infrastructures construction);
iii) Use phase (operation and maintenance) and vi) the Deconstruction phase (End of Life).

Therefore, in line with the goals defined in 4.2, the analysis is focused on the issues highlighted in the colored box in table 2, taking into consideration only 2 main lifecycle stages: process and use.

**Table 2.** Physical elements for the different fields of the built environment (readapted by authors from [8])

| | **PHYSICAL ELEMENTS** | | |
|---|---|---|---|
| | **BUILDINGS** | **OPEN SPACES** | **NETWORKS** |
| **MITIGATION MEASURE** | Insulation of the building's envelope | Reduce the heat island effect | District heating |
| | Replacement of windows | Green areas | Photovoltaic electricity in place of fossil fuels |
| | Reduced use of water | Parking lot | Waste collection and management services |
| | Reduced lighting consumption | | Replace I-bulb sales with LEDs/CFLs |
| | Reduced energy consumption | | |

▨ Elements assessed in the LCA

### *4.2.3 Assumption in the case study related the Life Cycle Inventory*

The foreground flows are principally represented by real data collected during site visits, interviews and re-calculations based on appropriate software (e.g. energy related retrofit of buildings). Whenever primary data were not available, regional and national references sources were considered as shown in table 3.

**Table3.** Foreground flows output and waste

| | **Foreground flows Output and Waste** | | | |
|---|---|---|---|---|
| | **Electricity** | **Natural gas** | **Water** | **Waste** |
| Reference unit | $m^2$ of living space | $m^2$ of living space | $m^3$/ inhabitant | $m^3$/ inhabitant |
| Typology of data | Primary data | Primary data | Secondary data (source: Hera*) | Secondary data (source: ISPRA**) |

*Multi-utility company that provides water and energetic services in the Bologna municipality) Italian **Institute for Environmental Protection and Research)

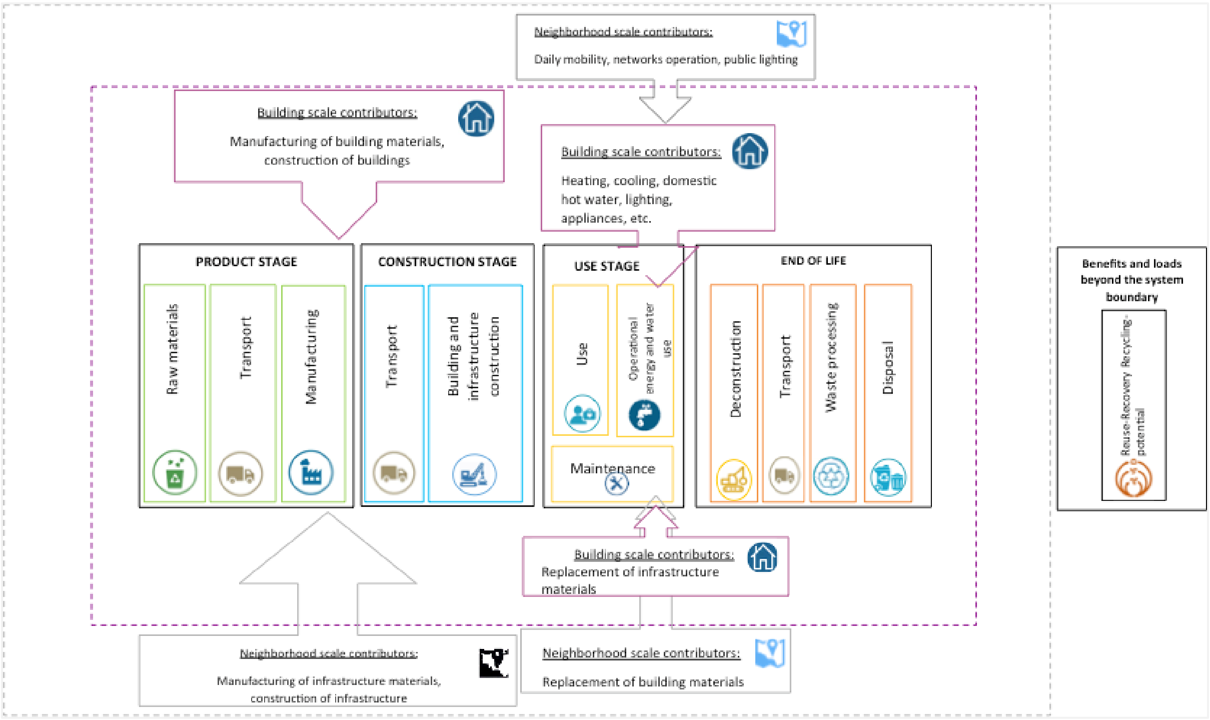

**Figure 5.** Neighbourhood life cycle steps and associated contributors at both building and neighbourhood scale (readapted by authors from [8])

The Life Cycle Assessment of almost all physical elements was performed using the Simapro© software [20] and the Ecoinvent database v.3.5 (2019). While Environmental Performance Evaluation for replace the windows in the building and to reduce the heat island effect in the open space was carried out adopting the impact indicators avowed by the related manufacturers in the Environmental Product Declarations (EPDs) [21-22]. Results showed in this paper are focused on only one impact indicator (Global Warming Potential, measured in kgCO$_2$-eq).

## 5. Streamlined LCA of retrofitting the block of Bolognina urban district

Outcomes provided in Figures 6 and 7 are related to only one of all the assessed LCA indicators. More specifically, Figure 6 provides the Global Warming Potential [kg CO$_2$ equivalent] related to the environmental impacts of the LCA applied to retrofitting the block of Bolognina neighbourhood associated to the two life cycle stages (product and use stage) in 1 year, while Figure 7 is referring to the entire Building's life cycle (reference service life value from [25]).

Although limited to the GWP indicator and restricted to two life´s stages only, the improvement due to the mitigation strategies is evident. The decrease of kg CO$_2$ equivalent is about 59% of the total value. It can be further appreciate if you consider the entire life cycle as it is highlighted in the Figure 7, in which is showed the increase of CO$_2$ value (vertical axis) in the years (horizontal axis).

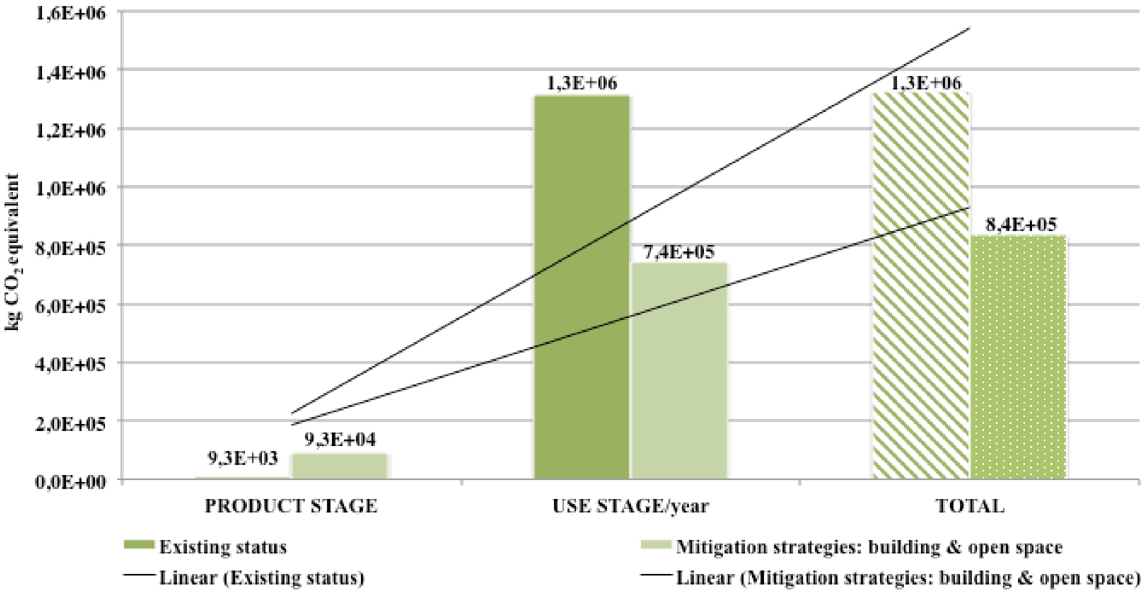

**Figure 6.** Comparative assessment related to Global Warming Potential (kg $CO_2$ equivalent) between existing status and mitigation strategies of the block of Bolognina neighbourhood in 1 year

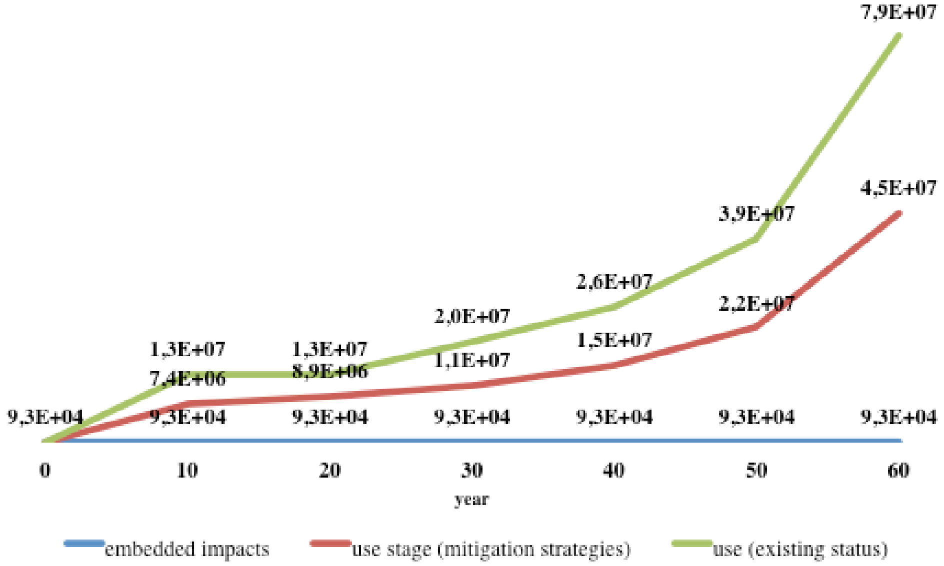

**Figure 7.** Comparative assessment related to Global Warming Potential (kg $CO_2$ equivalent) between existing status and mitigation strategies of the block of Bolognina neighbourhood during entire Life Cycle of Building (60 years)

More specifically, at building level the applied mitigation strategies have led to the reduction of energy consumptions in the building's use phase -heating, cooling, tap water and hot water- (i.e. 43,4% kg $CO_2$ equiv.), but increasing the embedded carbon generated in manufacturing of the materials used. However, total GHG emissions from mitigation strategies remains below the level of the existing status (37,8%). Likewise, actions on the open space (reduction of the heat island effect and drop of electricity consumption for public lighting) decreased GWP by ca. 41% (-52,1% in the use phase and + 90% in the product stage). As a first application, of a simplified application of LCA on an urban block, this study shows the potentiality of this methodology in the evaluation of the environmental performance of the built environment at urban scale. Next step will extend the evaluation to cover all other life cycle stages, but further researches are needed to complete the evaluation and to assess the three pillar of sustainability throughout a life cycle sustainability assessment.

## 6. Conclusions

Environmental assessments and, in general, the sustainability are nowadays relevant of most thematic areas, and particularly cities. Despite the evident irreversibility of environmental impacts like global warming, biodiversity and resource depletion, the environmental accounting in the building and urban sectors is presently based on subjective approaches and less precise [26].

Limited and simplified assumptions have been used in the present study focused chiefly on the methodologic implementation, but greater variation in context conditions would be useful to support a comparison of alternatives, notably in the design phase.

In terms of method the comparability among the case studies above all requires harmonization of the functional unit considered.

At the neighbourhood level, this is huge and complex, since that include elements different both as size that like typologies: buildings, infrastructure, public space.

Necessary gaps and implementations to build a complete and harmonized framework are presently showed from a recent study on the current state of the art [27].

Yet for application method improvement and to bridge the existing gap considerable efforts have still to be made.

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