Urban retrofit of the Leipzig-Grünau District. A screening LCA to measure mitigation strategie

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Abstract. The work proposes and verifies an integrated approach to the redevelopment of the disadvantaged Grünau district in Leipzig, combining microclimatic mitigation strategies on buildings and urban scales with Life Cycle Assessment screening. The application of the LCA showed that, compared to an increase in the impact of retrofitting solutions, the strong reduction of energy consumption (-58%) during the use stage leads to an overall decrease of the total GWP. Nonetheless, some major issues connected to occupant comfort were not totally captured by the environmental dimension. Consequently, it is crucial to develop new approaches and schemes based on combining LCA with other appropriate performance criteria in order to more broadly assess the sustainability of a district.

Keywords: City transformation; Urban retrofit; Life cycle assessment; Environmental impacts; Outdoor and indoor comfort level.

Achieving an environmentally friendly and habitable urban district

Climate change can have devastating consequences. To mitigate them we must start drastically reducing anthropological greenhouse gas (GHG) emissions. Many studies (Birgea and Bergera, 2019; Albino *et al.*, 2015) point to cities as one of the main contributors to climate change. While their sprawl only covers 2% of the world's landmass, urban areas are the leading hotspots of resource usage and environmental impact (Lotteau e*t al.*, 2015). Around 70% of global primary energy is consumed by urban areas, accounting for over 70% of global CO_2 emissions (Mauree *et al.*, 2019). Furthermore, more than half of the world's populations live in cities, and this figure is expected to grow in future decades due to rapid urbanisation and to the increase in populations migrating from rural to urban societies (Xu *et al.*, 2019). However, cities can also become sites of environmental efficiency and have the potential, through energy, building, mobility and planning mitigation strategies, to reduce major GHG emissions and energy consumption (Milhahn, 2019).

As a result, the United Nations has periodically debated the need for urban planning activities to explore new models and integrated growth strategies for a resilient environment. In 2016, the New Urban Agenda was collectively adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III), as a contribution to the application of the 2030 Agenda for Sustainable Development. Its purpose was to consider the multiple impact levels of urban areas and their short and long-term consequences with a view to achieving a sustainable environment, a competing economy and a better quality of life (Milojevic, 2018). Consequently, many German cities have developed new initiatives in an attempt to enhance their adaptive and urban resilience abilities. One of these cities was Leipzig, which since 2016 has updated the concept of integrated urban development through the 2030 INSEK-Leipzig plan, encompassing the idea of sustainability. While developing this plan, the Grünau district was identified as one of the most disadvantaged areas of the city, having heavily suffered the consequences of population decline resulting from German reunification, which left the neighbourhood with half of its pre-reunification population (Stadt Leipzig, 2016).

The crucial issues that need to be addressed to make this district sustainable are principally those concerning the ageing of buildings, along with rising environmental and energy-related values and improving the urban quality.

As a result, our study first analyses the main issues at the urban scale and proposes several mitigation strategies that seek to enhance the sustainability of the district. Accordingly, with the aim of evaluating the suitability of the defined urban retrofit strategies, the Life Cycle Assessment (LCA) methodology was applied at two different scales. While LCA was used to conduct quantitative assessments of buildings in order to identify and measure the environmental impact produced over the course of their entire life cycle, its application at urban level is so far limited and being studied by LCA specialists (Lotteau *et al.*, 2015; Palumbo *et al.*, 2019). A secondary objective of the research was to identify whether this method could provide strong scientific grounds to evaluate the environmental issues of urban districts.

Description of the case study: issues at district and building scales

After a period of depopulation following the German reunification, Leipzig is currently the city of the former GDR with the highest population growth. This trend leads to an urgent need for new housing and the redevelopment of existing buildings. A district particularly affected by this phenomenon is Grünau. This working-class neighbourhood was built between the 1960s and the 1980s with 38,000 housing units for about 85,000 inhabitants. Therefore, Grünau has big potential for urban and housing development and has been the focus of several studies and integrated development plans.

In order to identify the principal issues of this district and to develop some appropriate mitigation strategies, several analyses and measurements at district and building scale have been carried out.

Four-lane streets divide Grünau into "green pedestrian islands", where there are large residential buildings. Noise analyses (Fig. 1) have shown that the main sources of noise are vehicle traffic as well as tram and metropolitan trains. Air quality surveys, conducted by the municipality of Leipzig, have shown that the values of air pollution (in particular PM10 and PM2.5, NO, NO_2, SO_2 and volatile organic compounds like benzene toluene/xylene) are higher near the main roads but in any case below the maximum permissible values. In order to evaluate the microclimatic conditions of the site,

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01 | Noise mapping, showing the different forms of noise

02 | Identification of the analysed areas

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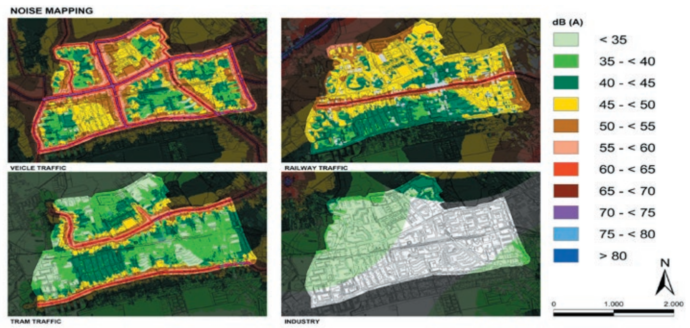

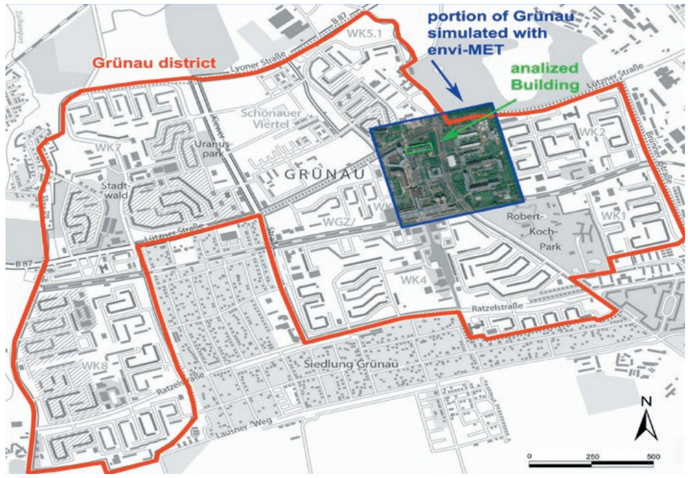

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the climatic data of the last 30 years was generated with the software Meteonorm and verified with that of local meteorological stations. Based on these values (station and interpolated data), hourly values for a "typical meteorological year" and a "representative summer and winter day" were calculated with Meteonorm using a stochastic model, resulting in a climate data input file for the simulations. These analyses have shown a constant increase in temperature and humidity during summer months and the intermediate seasons over the last 15 years. Analyses of the shading of the buildings as well as of the outdoor spaces are carried out through the elaboration of solar diagrams. The comfort level of the outdoor spaces was simulated with ENVI-met, a three-dimensional non-hydrostatic computational fluid dynamics software for analysing interactions between buildings, surfaces, plants and air within urban environments. The part of the district chosen for the environmental simulation measures 500x500 metres and is quite heterogeneous in order to assess different situations, such as a road with heavy traffic, multi-story residential buildings and green areas, among others (Fig. 2). The outdoor comfort conditions in the districts were simulated for two separate days: one in summer (21st June - summer solstice) and one in winter (21st Dec. - winter solstice) as these are the days with the lowest and the highest level of sun radiation. The simulations calculated a period of time from 6:00 a.m. to 6:00 p.m. The analysed microclimate parameters are: air temperature [K], relative humidity [%], wind velocity [m/s], wind direction [deg], surface temperature [K] at the building surfaces and the ground flooring. The analysed comfort parameters are: physiologically equivalent temperature (PET), Predicted Mean Vote Index (PMV), Predicted Percentage of Dissatisfied Index (PPD), and Universal Thermal Climate Index (UTCI).

The simulation results (Fig. 3) show the values of PMV and PPD on 21st June at 2:00 p.m. (the "longest day" at the "hottest hour"). The figure highlights that in summer, especially in areas that are directly exposed to the sun, there are situations of discomfort and that the presence of greenery (lawn) is not sufficient to mitigate the increase in temperature due to climate change in recent years.

Following a detailed analysis of all the above mentioned environmental parameters, it was found that the discomfort phenomena, measured with PMV and PPD values, derive mainly from direct radiation and low air movement. In fact, the operating temperature is not extremely high (max 26 °C) and the relative humidity is acceptable (average value of 45%).

The objects of this study at the building scale are two 11-storey blocks (48 m long and 33 metres high) built with mass-produced prefabricated concrete panels based on a regular grid and located in the Grünau-Mitte district (Fig. 2, 4). The analysis of their building characteristics and energy efficiency (using onsite tests and thermography surveys) showed inadequate energy efficiency (poor thermal insulation, inefficient solar shading and presence of thermal bridges), acoustics and fire protection.

The mitigation strategies adopted

On the basis of the highlighted issues, mitigation strategies were identified to improve the level of outdoor comfort and building quality (Fig. 5).

Urban-scale strategies were based on an overview of the whole district, seen in its complexity (Rossi, 2017).

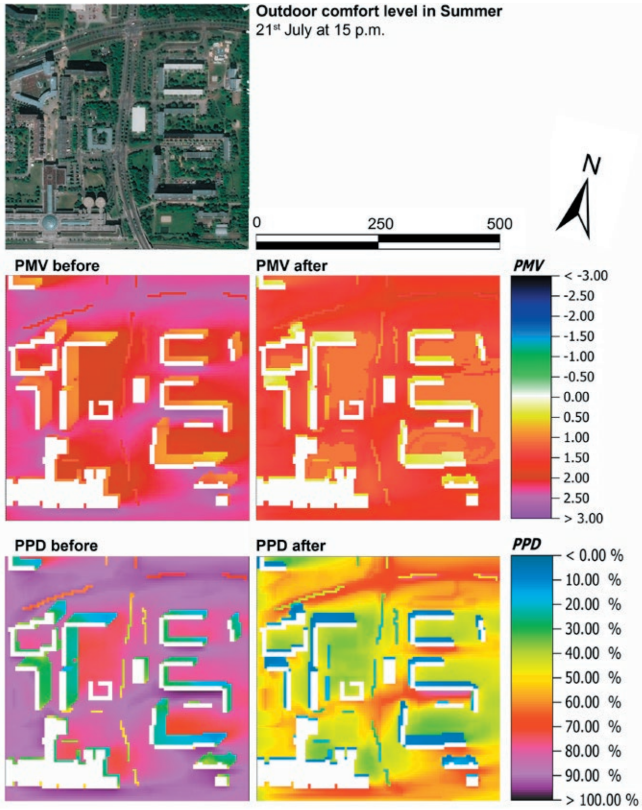
In order to improve acoustic comfort, the installation of green acoustic barriers or evergreen trees near main roads is planned. These barriers, in addition to limiting noise, help to improve air quality, reduce pollution, provide shade and enhance the local outdoor comfort level with increased humidity through evaporation. To reduce the heat island effect, mainly occurring in the square in front of the shopping mall, the use of appropriate cool paving materials and solar shading systems, such as sun sails, has been planned. Public lighting, at times poor and inefficient, will be replaced with high efficiency LED lamps, and limited accessibility will be improved through the redevelopment of pedestrian paths and the construction of ramps.

The ENVI-met simulations (Fig. 3) show how mitigation strategies at the urban scale (Fig. 5) significantly improve both the PMV-index and the PPD-index.

At the building scale, the intervention strategies aim to complete the previous renovation project through work on the systems and on the envelope to improve the general energy efficiency conditions. In order to reduce significant energy losses caused by obsolete concrete panels and single-glazed wooden window frames in the envelope, the window frames will be replaced with double-glazed and thermal-cut PVC frames, and mineral wool thermal insulation (10 cm thick) will be attached to the outside walls.

03 | Analysis of the outdoor comfort level in summer before and after the application of mitigation strategies

04 | BIM-Model of the analysed building with information on its energy efficiency. Issues and mitigation strategies at district and building scale



The use of high efficiency LED lamps and appliances should reduce energy consumption, while the inclusion of rainwater recovery systems and renovation of the sanitary water system will reduce water consumption.

Investigating sustainability in an urban retrofit with a life cycle approach

With the intention of properly assessing the effectiveness of the retrofitting solutions proposed in Grünau from a sustainable development perspective, it was decided to apply LCA. The LCA excels as a methodology capable of measuring sustainability as it is the most reliable framework for verifying the potential environmental impact of a product (Schlanbuscha *et al.*, 2016), in addition to being standardised by ISO 14040:2006 and 14044:2018, and more specifically for buildings and construction products by ISO 15978:2011 and EN EN15804:2012+A2:2019. In recent years, LCA has been increasingly recognised and used by several stakeholders in various economic sectors, also becoming a reference methodology to support policy decisions. In the EU context, the Single Market for Green Products (EC, 2013) or the EU Better Regulation Toolbox (EC, 2015) are two important community initiatives that reflect this trend (Zampori *et al.*, 2016).

In practice, many Green Building Rating Systems (GBRSs) have developed new planning tools to support the measurement of sustainability at the urban level. Some of them, for instance the German Sustainable Building Council (DGNB Urban Districts), have also implemented the LCA with their own approaches and assumptions to assess environmental performance. As such, approximately 30% of the environmental quality score in the DGNB (UD) depends on the completion of an LCA. However, only the basic performance data of the building, mainly energy, water and waste management, is considered in the LCA.

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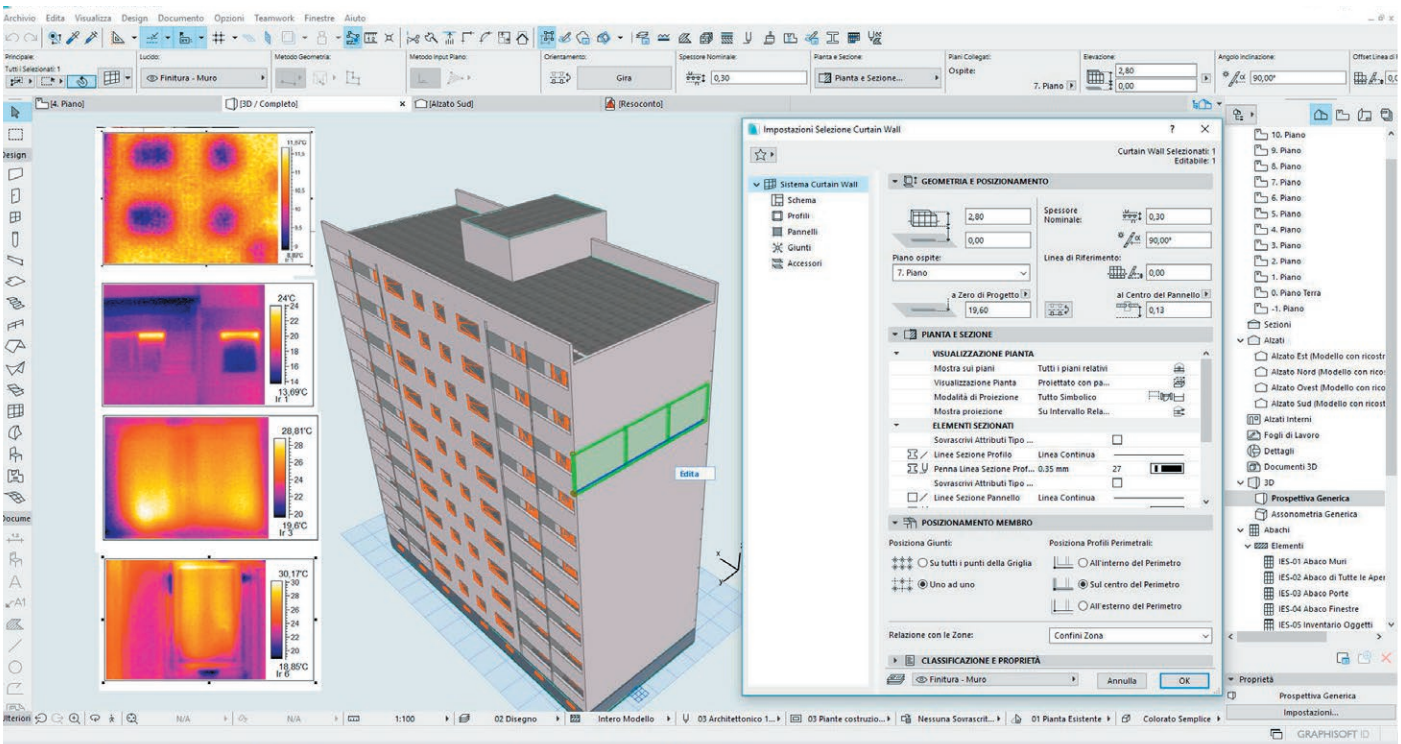

05 | Issues and mitigation strategies at urban and building scale

06 | Comparative assessment related to Global Warming Potential (kg CO_2 equivalent) between existing status and mitigation strategies of Grünau in 1 year

07 | Comparative assessment related to Global Warming Potential (kg CO_2 equivalent) between existing status and mitigation strategies of Grünau during the entire Life Cycle of the Building (60 years)

The identification of factors that act as significant contributors within the LCA of an urban district is first dealt with by Popovici (2006), and then broadly taken over by the framework developed by Lotteau et al. (2015). Popovici's model considers four main elements of the neighbourhood: buildings, open spaces, network and mobility. However, due to the considerable number of variables and interactions in a district model, a set of adaptations and assumptions is required to make the methodology implementable.
Consequently, this study conducts a screening LCA, following the indications described in the Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative (EeB Guide, 2012) and focusing on the environmental dimension. The EeB Guide describes screening LCA as an assessment that provides an approximate evaluation of the environmental performance, with an initial examination of the potential environmental impact. However, the results obtained do not provide detailed information on the environmental performance, nor, according to ISO 14044, can the screening LCA be used to make comparisons.
More specifically (Tab.01) the following assumptions were made in this study: i) only five crucial mitigation strategies were assessed; ii) only two stages of the LCA were considered: production and use stage; iii) only one life cycle environmental indicator was evaluated: Global Warming Potential (GWP).
In order to facilitate a comparison between the two LCA scales, the equivalent functional unit (FU) must be specified, defined by LCA criteria as the quantified performance of a product system used as a reference unit whenever a comparison between assertions is made (ISO 14040-14044). Literature highlights the need to adopt a per capita FU (m^2 of living space/inhabitant) when applying LCA at neighbourhood scale. Nevertheless, the assessment also considers the dimensional aspects of the block located within the area studied and it is evaluated for 60 years in accordance with the European Framework Level(s) (Dodd *et al.*, 2017). Our FU includes precisely 2,700 m^2 of open area, 28,203 houses with 1,013,603.1 m^2 of living space and 43,904 inhabitants.
The LCA was approached first at building scale, focusing on the retrofitting solutions proposed: windows and insulation improvements, as well as the reduction of water consumption and heat energy demand. Secondly, the LCA related to the Open Spaces field was carried out, focusing on three mitigation strategies: the installation of green acoustic barriers, the use of high efficiency LED lamps, and the replacement of paving in the square.
The software used to perform the LCA of most of the physical elements was Simapro© and the Ecoinvent database v.3.5 (2019), while the environmental profile of replacing the windows, thermal insulation in the building envelope and cool paving materials was derived through the impact indicators contained in the specific Environmental Product Declarations of manufacturers.

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	Issues	Mitigation strategies
DISTRICT SCALE	Noise near the train tracks and main roads	- Application of green acoustic barriers - Planting of Tree
	Heat island effect in the square close to the to the shopping mall	- Replacing the flooring
	High PMV values in Summer in the green outdoor spaces	- Tree-planting - construction of roofs or solar shading systems such as sun sail
	Sometimes poor and inefficient public lighting	- Use of high efficiency LED lamps
	Sometimes limited accessibility	- Redevelopment of pedestrian paths - Construction of ramps
BUILDING SCALE	Partly low level of renovation (1990)	- Joints sealing - Fire prevention system regulation
	High energy consumption	- Replacement of heating systems - Use of high efficiency LED lamps
	High water consumption	- Insertion of rainwater recovery systems - Update of the sanitary water system
	Thermal dispersions of the envelope	- Replacement of windows - External insulation of the facade
	Under-sizing of rooms	- Insertion of new balconies - Replacement of existing balconies

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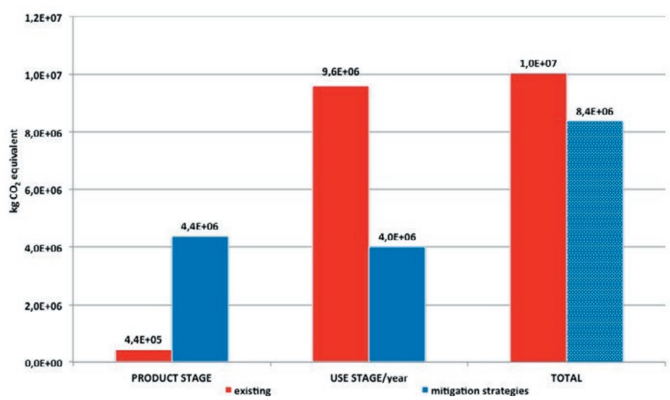

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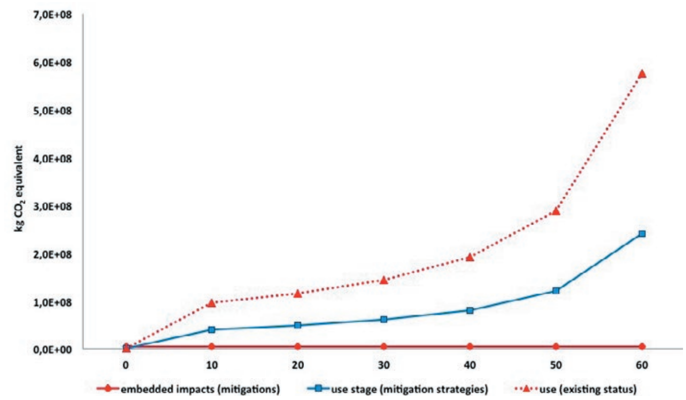

Tab. 01 | Assumption adopted in the Screening LCA in accordance with the EeBguide (Gartner *et al.*, 2015)

| Tab. 01

	Assumption at Urban level	Assumption at Building level
Purpose	• Noise pollution reduction; • Heat island effect reduction; • Public lighting improvement	• Energy efficiency improvement • Water consumption reduction
Indicator analysed	Global Warming Potential (GWP)	
Data Requirements	• Open spaces (roads, sidewalks, parking lots and green areas); • Public lightning consumption District heating; • Dimensional characteristics; (e.g., open spaces, surface inhabitants, no. of dwellings)	• Building (two 11-storey blocks); • Natural gas consumption; • Heating energy demand; • Water consumption; • Dimensional characteristics (e.g., windows and walls surface, type and insulation)
Mandatory Life Cycle Stages	• A1-A3 (Product stage) • B6 (Operational energy use), B7 (Operational water use)	
Scope of the assessment	• Green acoustic barriers installation; • Replacing of the flooring. LED lamps implementation	• Improving energy efficiency of envelope (e.g., wall insulation, replacement of old windows); • Rainwater recovery systems and sanitary water system improvements; • Heating systems replacement

Discussion and future scenarios: the vision of technology experts

The LCA results relate to just one indicator: Global Warming Potential, expressed by equivalent kg of CO_2. In particular, Figure 06 shows the GWP related to the environmental impact of the LCA applied to retrofitting a block in Grünau in one year, associated with two life cycle stages: product and use stage. The product stage refers to the impact generated during the manufacturing of the products used. Consequently, the GWP of the product stage indicates, for example, the kg CO_2 emitted to produce the thermal insulation and the windows used in the retrofitting of the envelope, or the cool paving material used to reduce the heat island in the square. The use stage, on the other hand, considers, respectively, the operational energy usage (heating and water) and energy consumption from outdoor lighting in the open space.

The LCA results highlight that, against an increase in the impact owing to the materials and products used in the retrofitting solutions (product stage), the strong reduction of energy consumption (-58%) during the use stage leads to an overall decrease in the total GWP.

Figure 07 shows the outcomes related to the entire life cycle, considering 60 years in line with the indications of the European Framework Level(s).

More specifically, in the applied mitigation strategies the 52% increase in GWP generated in the manufacturing of the materials and products used is offset by the reduction (roughly 58%) of energy consumption in the building's use phase: heating, tap and hot water. Although the comparative assessment reveals only one of the LCA indicators (GWP), and is limited to only two life stages, there is a clear improvement thanks to the mitigation strategies. The decrease in kg of CO_2 equivalent is about 58% of the total value. However, while carrying out the LCA, it was identified that some environmental impact cannot be fully evaluated due to the necessary limitations. For instance, although environmental impact from the construction of the acoustic green barriers could be determined, in order to evaluate the sustainability of the district after the application of the analysed mitigation strategies, a broader approach should be taken.

With the aim of evaluating the potential environmental impact associated with the mitigation strategies at the urban scale and measuring the effectiveness in terms of the reduction of carbon emissions before and after, this research has combined retrofitting solutions adopted in the Leipzig-Grünau district with a screening LCA.

In fact, the LCA results have provided a better understanding of the environmental impact on the whole intervention during the main life cycle stages (product and use stage, respectively), making it possible to conduct an initial and quick estimate of the environmental impact, and to determine the significant stages that need to be addressed to enhance sustainability.

Likewise, it was identified that some mitigation strategies proposed at urban level to improve sustainability, such as enhancing acoustic well-being or lessening the heat island effect, were not entirely captured or quantified by adopting a single approach.

For instance, improved sound insulation through the inclusion of acoustic green barriers can be determined as an environmental impact ("embedded impact" during the manufacturing stage), while the benefits obtained by increasing sound performance comfort can be better achieved at the level of social performance criteria, for example by including an EN 16309 "Sustainability of construction works Assessment of social performance of buildings-Calculation methodology" (Dolezal, Spitzbart, 2017) evaluation in the LCA.

Although the GBRS protocols already include central aspects, such as indoor air quality, thermal characteristics and all performances related to "health and comfort", there is no procedure to systematise them that would perceive the results, impact and benefits, and really connect with the LCA issues.

However, even though the application of LCA methodology at the urban level involved making a large number of assumptions, and consequently some results might not be as accurate as they should be, the analysis successfully identified the potential environmental impact related to the main urban issues, as well as specific mitigation strategies proposed to enhance the sustainability of the district and to identify the most relevant Life Cycle stages that need to be addressed in order to improve the environmental sustainability of Grünau. Furthermore, it provided a recognisable comparison between different statuses of the same neighbourhood (existing vs. mitigated). Therefore, it is thought that further development of this methodology could play an important role in the transition to low-zero carbon societies.

Consequently, it is crucial to develop new approaches and schemes based on combining LCA with social performance criteria in order to properly assess the sustainability of a district. A first step in this direction could certainly be to combine the results of the LCA with those inferred from the adoption of criteria and assessments on improved comfort performances in the use phase.

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