The definition of urban surface uses: a systemic approach for climate resilient and sustainable cities

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Abstract. In the current scenario of massive urbanization and global climate change, the United Nations' 2030 Agenda for Sustainable Development identifies among the main goals the necessity to make cities sustainable and resilient. The urban surfaces (i.e. streets, façades, roofs, etc.) are a key element in this process. Indeed, their exploitation offers the opportunity to increase resource efficiency, to produce renewable energy, to mitigate and adapt to climate change, and to reduce the overall environmental impact of cities.

Urban planning plays an essential role in defining the allocation of surface uses and ensuring their integration. This paper proposes an analytical framework to support planning decisions about the types of surface use allowable, their extent and location. First, urban surfaces typologies and their major cluster of uses have been classified. For each cluster, a set of criteria has been identified to evaluate the technical viability of its application. Finally, a workflow has been designed for characterising the most suitable surface uses in consolidated urban areas. The application of the proposed approach, which has been tested in Bolzano (Italy), is able to support the implementation of integrated policies aimed at achieving Sustainable Development Goals in cities.

1. Sustainable Development Goals in cities

Urbanization and growth of urban population worldwide are proceeding at an unprecedented rate. Half of the global population is living in cities and this share is estimated to reach up to 68% by 2050, resulting in around 6.5 billion urban inhabitants [1]. Urban areas are responsible for 60-80% of energy consumption and 75% of green-house gases emissions produced globally, despite occupying only around 3% of the earth surface [2]. This makes cities one of the major contributors to climate change and, at the same time, particularly vulnerable to its impacts, facing major weather and environment-related challenges [3].

In 2015, the United Nation (UN) Member States approved the 17 Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development aimed reducing poverty, improving health and well-being worldwide, and ensuring environmental protection [4]. Urban areas are directly targeted by Goal 11, which aims to “make cities and human settlements inclusive, safe, resilient and sustainable” [2]. However, due to their complexity, to the convergence of people and economic activities, and to their environmental impact, cities are key hubs of intervention, and can contribute widely in achieving all the SDGs. This study aims to discuss the relation between climate resiliency and sustainability objectives and SDGs, and the key role played by urban surfaces for their achievement in
cities. Furthermore, based on the categorization of the urban surfaces and their uses into well-defined classes, this work proposes an analytical framework for their systemic definition in consolidated urban areas.

1.1. Climate resiliency and sustainability objectives in relation to SDGs targets
In the current scenario of increased urbanization and global climate change, it is becoming crucial for cities to: (i) improve their environmental quality, (ii) protect people and infrastructures from extreme climate events, and (iii) use their resources efficiently, being self-reliant on energy, food, and water [5,6]. In order to set a clear framework, two main categories of objectives – climate resiliency and sustainability – are considered by the authors as essential for tackling SDG 11 in urban areas. Moreover, each objective contribute to several other SDGs’ targets, including, for example, poverty (SDG 1), energy (SDG 7), climate change and its impacts (SDG 13), and ecosystems and biodiversity (SDG 15). Table 1 illustrates the single objectives and their contribution to SDGs’ targets.

Table 1. Objectives of surface uses in cities and contribution to SDGs’ targets [4].

| Objectives                                      | Contribution to SDGs’ targets |
|------------------------------------------------|-------------------------------|
| **Climate resiliency**                          |                               |
| Urban climate regulation (C)                    | 11.5, 11.7, 13.1              | 1.5, 11.4, 13.2, 15.1       |
| Urban habitats and biodiversity preservation (HB)| 11.4, 15.1, 15.5, 15.9        | 6.6, 11.7, 13.1             |
| Urban water management (WM)                     | 11.5, 13.1, 15.1              | 1.5, 3.9, 6.3, 6.4          |
| Air quality amelioration (AQ)                   | 3.9, 11.6                     | 11.7                        |
| **Sustainability**                              |                               |
| Self-reliance on energy (E)                     | 7.1, 7.2, 7.3                 | 9.4                         |
| Self-reliance on food (F)                       | 2.4                           | 15.5                        |
| Self-reliance on water (W)                      | 6.1, 6.3                      | 6.4, 6.5, 6.6,             |

2. The role of urban surfaces
Urban surfaces and their characteristics can contribute in a consistent way to the UN 2030 Sustainable Development Agenda, tackling issues related to urban development, global climate change effects, and well-being of cities. The term “urban surfaces” encompasses all the surfaces that characterize physically and morphologically the built environment [7]. These include all the ground and building surfaces. Their categorisation is presented in Table 2.

Table 2. Classification of urban surfaces typologies.

| Ground surfaces | Building surfaces |
|-----------------|-------------------|
| Road network    | Roofs             |
| Sidewalks       | Flat              |
| Cycle paths     | Tilted            |
| Parking areas   | Curved            |
| Open spaces     | Other forms       |
| Public areas    | Flat              |
| Urban parks     | Transparent       |
| Spaces in-between buildings | Other forms |
| Façades         | Opaque surfaces   |
| Opac surfaces   |                    |
| Transparent     |                    |

2.1. Urban surface uses
In the latest years, urban surfaces are moving from being considered just as a cost, due to their maintenance, to a key opportunity for urban areas in increasing resource efficiency, exploiting renewable energy sources, and reducing their overall environmental impact [8,9]. These surfaces can be characterized by different materials and host several functions. The term “urban surface use” defines the
way a surface is deployed to address the urban resiliency and sustainability objectives discussed in Section 1.1. The main solutions, clustered in five main categories, are reported in Table 3, together with the objectives they contribute to.

**Table 3.** Surface uses categories, main solutions, and their contribution to climate resiliency and sustainability objectives.

| Uses                              | Objectives * | Primary | Secondary |
|-----------------------------------|--------------|---------|-----------|
| **Green solutions**               |              |         |           |
| Vegetation on ground              |              |         |           |
| City parks / Vegetation in-between urban spaces | C, HB, AQ    | WM      |
| Raingardens                        | C, HB, WM, AQ|
| Green building elements            |              |         |           |
| Vertical greening systems          | C, HB, WM, AQ|
| Horizontal greening systems        | C, HB, AQ    | WM      |
| Balcony gardens                    | C, HB, WM, AQ|
| Innovative technological green     |              |         |           |
| Microalgae-based biomimicry        | AQ           |         |           |
| Vertical plant filters             |              | C, AQ   |           |
| **Water solutions**                |              |         |           |
| Water bodies                       |              |         |           |
| Natural                            | C, HB, WM, W | AQ      |           |
| Artificial                         | C, WM, W     | HB, AQ  |           |
| Evaporative techniques             | C            |         |           |
| Water squares                      | WM           | W       |           |
| **Urban agriculture**              |              |         |           |
| Ground-based farming               | HB, F        | C, WM, AQ|
| Building-integrated agriculture    |              |         |           |
| Vertical farming                   | F            | AQ      |           |
| Edible walls / Rooftop farming     | F            | C, HB, WM, AQ|
| **Other practices**                |              |         |           |
| Hydroponics                        | F            |         |           |
| Aquaponics, Aquaculture            | F, W         |         |           |
| Apiculture                         |              | HB, F   |           |
| **Cool materials & Innovative solutions** |              |         |           |
| High reflective and emissive materials | C        |         |           |
| **Innovative materials**           |              |         |           |
| Thermochromic / Retroreflective materials | C    |         |           |
| Cool with integrated Phase Change Materials | C    |         | E         |
| Cool materials with photocatalytic properties | C, AQ |         |           |
| **Evaporative pavements**          |              |         |           |
| For the building envelope          |              |         |           |
| Photovoltaic (PV), Solar thermal (ST), building-integrates, and hybrid systems | E |         |           |
| **Energy systems**                 |              |         |           |
| For ground surfaces                |              |         |           |
| PV pavements, asphalt solar collectors, thermoelectric generation systems | E |         | C         |
| PV-integrated urban furniture      |              |         | E         |

*Climate resiliency objectives: urban climate management (C), urban habitats and biodiversity preservation (HB), urban water management (WM), and air quality amelioration (AQ)
Sustainability objectives: self-reliance on energy (E), on food (F), and on water (W)

2.2. Current approaches to the definition of surface uses
Nowadays, the common approaches to urban surfaces exploitation are sectorial; they focus on single solutions (e.g. urban vegetation [10] or use of reflective materials [11]), or on single objectives, such as heat mitigation [12], or storm-water management [13]. Moreover, the majority of such approaches does not consider the three-dimensional complexity of the built environment, but a bi-dimensional simplification [14]. While ground surfaces are already used for multiple purposes [15], the external
surfaces of the building are still considered merely as protective layer or space for hosting technical equipment [8]. However, it is estimated that roofs allocate approximately 20–25% of the total urban surface [16], while the façades are almost double [17]. Hence, an increased utilization may offer several opportunities for enhancing urban sustainability and resiliency, and providing environmental, social, and economic benefits [9].

A further problem in current approaches is a diffused lack of integration among solutions. AFor instance, considering roofs with adequate orientation, conflicts are arising between the surface uses for renewable energy production, urban agriculture, and green solutions [18]. In this scenario, urban planning may contribute in reducing conflicts and promoting the notion of urban surfaces as resources in the view of urban sustainability and resiliency [8]. However, there is the need for clear criteria and processes targeting the systemic definition of urban surfaces.

3. Systemic approach to surface uses definition in urban areas
The proposed analytical framework (Figure 1) aims at systematize the steps and criteria for the selection and location of surface uses, fostering their integration. The methodology starts from the characterisation of the area, both from the morphological and the environmental perspectives. The aim is double: (i) identify the modifiable surfaces (by applying the typologies proposed in Table 2) suitable for the application of new solutions, and (ii) understand the environmental performance of the area and its main vulnerabilities. The results from this step are used to inform the stakeholders and citizens involved in the design process, and to define, together with the priorities set by municipal plans, the main objectives to be pursued by the modification of existing urban surfaces. At this stage, the targets in terms of climate resiliency and sustainability (Section 1.1.) are prioritised through a multi-criteria analysis process. Based on these, the suitable surface uses are selected from the solutions’ portfolio presented in Table 3. The selection and the definition of surface uses location are carried out by applying two sets of criteria. The first one encompasses general criteria, defined by the authors for filling the existing methodological gap discussed in Section 2.2. The second targets the technical feasibility, and includes design parameters and recommendations collected from scientific literature [9,10,13,16–20].

4. Application to a residential case study in Bolzano (Italy)
The application of the proposed method is tested in an existing district in Bolzano. The city of Bolzano (UTM 46°29'53.8" N, 11°21'17.1" E) is located in the north-east of Italy; its climate is categorized as moist continental and is characterized by strong seasonal fluctuations, with high temperature and heatwaves during summer. For this reason, at municipal level, the priority for urban interventions is set on urban climate regulation, with a strong focus on the increase of vegetation and on the implementation of green solutions. The residential district selected as case study is one of the five areas in Bolzano taking part to the Smart Cities European project SINFONIA; the area covers 0.3 km² and includes two social housing blocks, being refurbished in the framework of the project, and the nearby buildings. Some results of the morphological and environmental characterisation of the area are shown in Figure 2, while Table 5 schematizes the distribution of surface typologies. Being summer heatwaves a recognized problem for the city, the air temperature distribution has been evaluated for a typical hot summer day.

Table 4. Overview of the distribution of urban surfaces in the case study area.

| Surfaces   | Material       | Area [m²] | Total area [m²] | Fraction over total [%] |
|------------|----------------|-----------|-----------------|------------------------|
| Ground     |                |           |                 |                        |
| Pervious   | Grass          | 64 000    | 76 200          | 15%                    |
|            | Bare soil      | 12 200    |                 |                        |
| Impervious | Asphalt streets| 40 000    | 137 000         | 27%                    |
|            | Pavements      | 97 000    |                 |                        |
| Water      | -              | 0         | 0               | 0%                     |
| TOT        |                |           | 234 000         | 42%                    |
| Building   |                |           |                 |                        |
| Façades    |                | 234 000   |                 | 46%                    |
| Roofs      |                | 63 000    |                 | 12%                    |
| TOT        |                |           | 397 000         | 58%                    |
Figure 1. Proposed analytical framework.
Figure 2. Case study area: characterisation and location of surface uses.
The total area available in the district (Table 5) demonstrates the importance of applying a three-dimensional approach, since a consistent percentage of is provided by building envelope surfaces, in particular by façades. Based on the analyses carried out, and on the municipal and local priorities, the main objectives to be pursued, in order of priority, are: i) urban climate regulation - mitigation of high summer temperatures, ii) energy production from renewable energy sources, and iii) increase of green areas in the district for environmental benefits and community well-being. These have been used as guide for the definition of the suitable surface uses, which are listed in Table 5 and schematized in Figure 2c. In the definition of surface uses, green and water solutions have been prioritized due to their contribution in mitigating summer temperatures; while, on the roof surfaces with suitable solar potential, solar active systems have been foreseen. On available flat rooftops (see Figure 2c), solar green roofs have been selected to combine biodiversity preservation and onsite renewable energy production, while providing also a range of environmental, health, aesthetic, and economic benefits [21].

Table 5. Characteristics of the urban surface uses selected in the case study.

| Use                      | Surface     | Solution selected                                                                 |
|--------------------------|-------------|-----------------------------------------------------------------------------------|
| Green solutions          | Ground      | Increase of vegetation: + 15 %                                                     |
|                          | Building    | Vertical greening systems – Green façade (leaf area density = 1.85 m²/m³) on surfaces exposed at south, and façades along the roads with higher T_air |
|                          | Road network| Horizontal greening system – Extensive green roof                                   |
|                          | Open areas  |                                                                                   |
|                          | Façades     |                                                                                   |
| Water solutions          | Ground      | Water basin (water depth = 2 m) close to Via Cagliari                              |
|                          | Building    |                                                                                   |
| Cool materials           | Ground      | Cool grey asphalt on the main roads (albedo = 0.40)                               |
|                          | Building    |                                                                                   |
| Energy systems           | Building    | BIPV on surfaces with suitable solar potential                                     |
|                          | Façades     | PV panels                                                                         |
|                          | Roofs       |                                                                                   |
| Integrated solutions     | Building    | Solar green roofs on available flat roof surfaces                                  |
|                          | Façades     |                                                                                   |
|                          | Roofs       |                                                                                   |

5. Conclusions
The main purpose of the study was to demonstrate the key role that the urban surfaces and their uses may play in enhancing climate resilience and sustainability of cities, and their contribution in achieving SDGs. To foster the definition of a systemic approach, first, the urban surface typologies have been categorized, and the main cluster of surface uses have been defined. Building on this, a framework for the definition of suitable urban surface uses, their location, and integration has been proposed. The methodology has been tested in a district located in Bolzano, demonstrating its role in supporting the implementation of integrated policies aimed at resource efficiency, and mitigation and adaptation to climate change.

Future developments of the study will include the more accurate definition of the criteria to evaluate the technical feasibility of each surface use application. Furthermore, a framework for the evaluation of the environmental performance of the solutions selected by applying the proposed methodology is needed for understanding the effectiveness of the solutions in the urban environment.

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