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A Socio-Spatial Extension of the Local Climate Zone Typology: Its Potential in Computational Planning Support Systems

Athanasios Votsis [1], Vuokko Heikinheimo [2], Milla Mikkola [3], Dina Babushkina [4], Aija Staffans [5], Tiina Merikoski [6], and Stan Geertman [7]

[1] Governance and Technology for Sustainability, University of Twente, The Netherlands
[2] Built Environment Solutions, Finnish Environment Institute, Finland
[3] Sustainable Urban Development, Ramboll Finland, Finland
[4] Philosophy, University of Twente, The Netherlands
[5] Built Environment, Aalto University, Finland
[6] Lundén Architecture Company, Finland
[7] Human Geography and Spatial Planning, Utrecht University, The Netherlands

Correspondence: Athanasios Votsis (a.votsis@utwente.nl)

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Abstract

Computational planning support systems (CPSS) have been invaluable for the transparent and rational planning of climate-resilient cities as they help clarify and optimise the trade-offs between alternative choices. CPSS have shown great promise also as digital design boards for the co-creation of new solutions. However, both as a tool and a theoretical stance to spatial planning, CPSS have suffered from top-down representations of urban space. Bottom-up, collective, and subjective processes essential for sustainable and climate-resilient urbanism are often left unaccounted for. This article introduces one possible solution to this gap, namely structuring the information flows of CPSS according to the local climate zone framework, enriched with urban commons information. We illustrate our approach with data from the 29 largest Finnish municipalities. We combine OpenStreetMap and demographic information with local climate zone data to produce a socio-spatially extended local climate zone typology of Finnish urban forms. The results delineate a Nordic angle to sustainable spatial planning—green and sparse, somewhat compact and mixed, but not comprehensively so, built environments—allowing a juxtaposition with normative ideas about sustainable cities. We furthermore propose a co-design workflow that is based on our typology. The main practical applications of our work include vulnerability mapping and integrated impact assessment, multimodal communication of computer model output, and computationally-assisted co-design of built environments with a variety of stakeholders.

Keywords
co-design; computational planning support systems; local climate zones; neighbourhood typology; social sustainability; urban commons

1. Introduction: Computational Spatial Planning and Social Sustainability

While significant progress has been achieved in articulating sustainable spatial planning paradigms across such urban subsystems as land use and transport, economic development, and environmental management, their social sustainability is often unclearly articulated. Evidence has shown that popular paradigms merely offset impacts from one domain to another (Sera et al., 2019) and they often increase the disadvantage of vulnerable groups (Anguelovski et al., 2016; Blok, 2020; Shirazi & Keivani, 2019). In addition, what renders a given spatial planning paradigm sustainable is a contested topic (Echenique et al., 2012; Hautamäki et al., 2024; Votsis & Haavisto, 2019), which is itself part of a wider problem of vicious circles in Sustainable Development Goals (SDGs; Fanning et al., 2021; Pham-Truffert et al., 2020). In this article, we focus on one aspect of the ambiguities of sustainable spatial planning approaches, namely, their relevance and impact on everyday life. Computational planning support systems (CPSS) adopt a prospective mentality to impact assessment (Ness et al., 2007), assessing proposed solutions before the fact of their implementation across an array of urban subsystems (Wegener, 1994), offering significant assistance in evaluating the real-world implications of normative sustainable planning paradigms (Geertman et al., 2013; Pelzer et al., 2014). This is important, when one brings to mind the diverse multisectoral and long-lasting impacts that urban planning interventions can have on cities.

However, there is still much to be done with incorporating into CPSS a wider diversity of SDGs, especially relating social, ecological, and governance dimensions to spatial organisation (cf. Wegener, 1994; see also Hillier & Hanson, 2003). Climate resilience has experienced a paradigm shift toward community and societal aspects (Intergovernmental Panel on Climate Change, 2012), with inclusivity, fairness, and equality taking a central role (Together 2030, 2018). In the urban domain, critical work on urban commons highlights that resilience also implies that successful responses in and through urban space have a pronounced informal, non-institutionalized flavour, in which the coping capacity of each group is given space to develop (Ostrom, 2010; Petrescu et al., 2016; Sassen, 2017). Indeed, open-source, adaptive, tactical, and do-it-yourself urbanism (Bradley, 2015), along with numerous other citizen-centric models of urban planning, have been proliferating, as they empower inhabitants and facilitate the crucial role of bottom-up processes in cities. Thus, for CPSS the issue at stake is the realistic and relevant representations of the socio-spatial nature of the urban fabric. If CPSS are to avoid mistakes of the past (Lee, 1973, 1994), it is not enough that they represent the formal institutionalised functions of urban space (e.g., land uses or house prices) but also its social functions (e.g., what daily activities occur or could be encouraged in certain land uses). Bottom-up social-organisational aspects have to be incorporated in CPSS (McCann, 2017), continuing and extending the example of participatory mapping as a means of co-creating the built environment (Grêt-Regamey et al., 2021).

Our article aims to facilitate this fusion of formal representations of the built environment with more informal, non-institutionalized aspects of socio-spatial sustainability and resilience. We present an approach that is useful in two ways. First, we contribute to the need to standardise and communicate different kinds of built environments in a manner that also accounts for bottom-up social components. Second, we aid the redefinition of CPSS as tools that bridge planning science with planning practice, aiding co-creation and co-design throughout the stages of the planning process.

2. Theory and Methods

2.1. Urban Models and Local Climate Zones

Wegener (1994) systematised the urban processes that can be represented with computer models in the context of ex-ante urban policy assessments (Ness et al., 2007). These involve land use, housing, population, travel, networks, goods transport, employment, and workplaces, with specific models focusing on interactions between one or more of these sectors. According to Wegener (1994), these are embedded in the wider natural environment, which anticipated the proliferation of interest in environmental aspects that followed soon afterwards.

A recent development in connecting land use, housing, and population to the environment is local climate zones (LCZs) by Stewart and Oke (2012). LCZs are a built environment typology, based on the vertical height, density, textures, and materials of buildings, as well as the greenness and ground permeability of their neighbourhood. Human activity is accounted for but to a minor extent, featuring primarily the distinction between industrial and non-industrial phenotypes. Combinations of these characteristics produce 10 types (LCZ 01–10). Types 01–03 represent compact high-rise (01), mid-rise (02), or low-rise (03) built environments with minimum vegetation and stone, brick, tile, and concrete (02) or concrete, steel, stone, and glass (03) as the prevailing construction materials. Types 04–06 represent open high-rise (04), mid-rise (05), or low-rise (06) built environments with ample vegetation and perviousness in the neighbourhood, with concrete, steel, stone, and glass (05) or wood, brick, stone, tile, and concrete (06) as the prevailing construction materials. Type 07 represents lightweight low-rises with non-vegetated natural ground. Type 08 represents large low-rise buildings with minimum vegetation in the neighbourhood, whereas type 09 represents a sparse pattern of small buildings within an ample natural environment. Type 10 represents areas with "heavy industry" attributes (including residential patches) with minimal vegetation and metal, steel, and concrete as the prevailing construction materials.

LCZs link the material form and construction of a neighbourhood to its microclimate, because the 10 LCZ types respond differently to weather, yielding different diurnal energy balances and thermal profiles. LCZs thus attempt a standardised bridge between urban planning and climate resilience practice. Importantly, the typology provides a way to connect a neighbourhood's spatial layout to the weather and climate-related impacts implied by its material form and composition. If a neighbourhood is composed of one or more LCZ types, urban microclimate models can incorporate this information directly and translate it into micro-meteorological parameters, notably concerning thermal comfort, energy, drought and precipitation, and the urban heat island effect (Masson et al., 2020). LCZs are thus a way to deepen the ability of CPSS to assess how urban form and land cover connect to climate-related implications, notably exposure and vulnerability to climate change impacts, and a neighbourhood's energy balance, use, or demand profiles. However, the standardisation of LCZs has a main implication: one still ought to understand how LCZs look in specific cities if any ex-ante sustainability assessment is to be conducted in a manner that realistically connects to local conditions and processes.

2.2. Sociotope Mapping and Urban Commons

The present study aims to enrich the semantic diversity of LCZs, focusing on socio-spatial extensibility (cf. Yin et al., 2022). Within the necessity for urban planning to connect with citizen-centred bottom-up urbanism processes, and while the LCZ typology provides a link to urban climate, the link to human processes needs further elucidation. We operationalise our approach to fill this gap in CPSS by utilising "sociotope mapping." Ståhle (2006), drawing from Harvey (1989), distinguished between two major lenses through which architects and planners approach urban design and planning within a larger grid of spatial practices. On one hand, the built environment can be approached as a space of "domination and control," where top-down representations of urban space hold the major role through, e.g., land use, real estate property, or zoning maps and urban plans. However, as Ståhle (2006) also notes, this approach overlooks the dynamism that characterises the intentions, emotions, habits, and everyday practices attached to urban spaces as urban life unfolds. This highlights a second approach to the built environment, where "accessibility and distanciation" and "appropriation and use" are prominent lenses. Representations such as traffic analysis and space syntax are prominent in the former, whereas representations such as building typologies and sociotope maps are key for the latter. Within these bottom-up representations of urban space, Ståhle (2006), drawing from Lefebvre (1992, 1996), further distinguishes between lived (e.g., crime statistics on a map), perceived (e.g., sociotope map), and conceived (e.g., security zone map) space.

While LCZs reinterpret traditional land use representations of urban space into the domain of lived space, a further step can be achieved by extending them into the domain of perceived space through sociotope mapping. In this way, urban spaces are not represented exclusively in terms of their formal land use types—as typically done in CPSS—but can convey information about dimensions that are known to be essential for thriving and resilient cities (cf. Jacobs, 2011; see also Sassen, 2017): the social functions, everyday uses, and perceptions of urban space.

In this article, we adopt the idea of sociotope mapping and add to it elements of Ostrom's (2010) theory of the commons. Ostrom (2010) maintained that the sustainability of common goods—in our case, urban public spaces—is often being achieved throughout the world via bottom-up initiatives based on trust, reciprocity, and collective management by the community itself. Ostrom argued that this governance model is a successful alternative to market-based approaches to sustainability. The commons have proliferated in theory and practice, with a literature corpus of tremendous size that moves beyond the scope of our article. Nowadays, the notion has been extended to include the so-called "new commons," that is, common goods beyond the traditional domain of natural resources. A prominent category of new commons is the urban commons. Like sociotopes as a representational approach to perceived spaces, urban commons emphasise socio-spatial processes, with scholarship focusing, among others, on the informal and often non-institutionalized uses of public and private common spaces in cities. This often reveals the inconsistency between the originally intended uses of the built environment and the everyday ones by its users. Especially in moments of crisis, seeing the built environment through the lens of urban commons shows the potential that the reinterpretation and reappropriation of urban spaces have—outside prescribed or even legal uses—for giving vital room for local solutions to societal resilience, particularly by vulnerable citizens (Adianto et al., 2021). It is crucial to represent this bottom-up potential in CPSS.

Empirically, Ståhle's (2006) original sociotope mapping utilised observational fieldwork, which offered a depth of perceptual information for a well-defined urban area. In this article, we are proposing an alternative approach that can operationalise sociotope mapping in metropolitan, regional, or multi-city settings, where limited resources cannot allow large-scale in-depth fieldwork. Drawing from Ostrom (2010), Agyeman et al. (2013), and Boydell and Searle (2014), we adopt three dimensions to understand the potential of a neighbourhood for urban commoning: ownership, access, and rivalry surrounding an urban common. We especially draw from the study of Boydell and Searle (2014), who focused on the intersection between urban commons, property rights, and their implications for the citizens' right to the city. Ownership is operationalised as public or private urban commons, grounded on the fact that urban commoning does not happen only in public spaces such as a public square, but also in "public" areas of nominally private spaces such as the public area of a shopping mall. Access is operationalised as exclusive or nonexclusive in order to reflect the fact that access to either public or private common spaces may or may not be normally restricted by exercising (or not) the rights that follow from ownership of the space. Rivalry is operationalised via the scarcity of an urban commons within the boundaries of a neighbourhood, as the number of the neighbourhood's dwellers per the number of instances of the urban common resource. For comparability of neighbourhoods of various sizes across Finland, we normalised scarcity to 0–100%, with higher numbers denoting higher rivalry potential. While this operationalisation hinges on the assumption that most of the use of an urban commons occurs in its vicinity, which is not always true due to urban mobility and the purely administrative nature of neighbourhood boundaries, it assists in capturing a foundational component of urban commons, namely tensions and contestations surrounding their use. Putting these dimensions together, we develop a commons-based representation of urban space as public or private versus exclusive or nonexclusive, which leads to four categories (private exclusive, private nonexclusive, public exclusive, and public nonexclusive), which are further characterised in terms of their rivalry potential due to scarcity. These categories aim to operationalise foundational notions of urban commons as discussed by Ostrom (2010), while also relating to key notions of the theory of public goods (Gruber, 2022).

2.3. Implementation in Finnish Cities

The LCZ classification of Finland was retrieved by accessing the work of Demuzere et al. (2019). This is a raster representation that applied machine learning methods on multisource land use data to develop a 100-by-100-metre categorisation of continental Europe into the various LCZ types. Missing urban areas on near-coast islands of Finnish cities were filled-in from the original ECOCLIMAP dataset of Faroux et al. (2013). We produced a dataset of LCZ types for the largest Finnish cities, namely the greater Helsinki metropolitan area (municipalities of Espoo, Helsinki, Kauniainen, Kotka-Kouvola, Riihimäki, Sipoo, Vantaa, and Vihti), and the cities of Hämeenlinna, Joensuu, Kuopio, Lahti, Oulu, Pori, Rovaniemi, Salo, Tampere, Turku, and Vaasa-Seinäjoki. In order to produce a demographic characterisation of each LCZ type in Finnish cities, namely the gender and number of residents typically found in each LCZ type, we appended to the LZC pixels information found in the 250-by-250-metre gridded demographic dataset, produced by Statistics Finland (2020). In order to harmonise the scale inconsistency between the LCZs and demographic data, we used a spatially weighted version of the spatial overlay analysis, where the population and gender numbers in each 250-metre demographic pixel were distributed into the overlapping 100-metre LCZ pixels in proportion to the degree of aerial overlap between each demographic and each LCZ polygon.

Implementation of the urban commons approach discussed in Section 2.2 was achieved by using data from OpenStreetMap (OSM). OSM is a free editable world map that is generated by a global community of mappers. OSM data are used in various urban applications to map streets, buildings, green spaces, amenities, and activities (see Boeing et al., 2022). While OSM data may have gaps, it is overall the most extensive openly available data set on urban features. In Finland, OSM data are used, e.g., in regional journey planning applications increasing the motivation of the local mappers to keep the map contents up to date. We retrieved point-of-interest data related to sports and leisure facilities, historic locations, shops, and various other amenities (see the full list of features in the Supplementary Material, Workbook S2). We used a custom Python algorithm based on the OSMnx Python package (Boeing, 2017) to access the data via the Overpass Application Programming Interface. The algorithm and the retrieved OSM data from Finnish cities are available online at Heikinheimo (2025). In total, we retrieved data points under approximately 100 tags from OSM. These were categorised according to the access and ownership dimensions (see Section 2.2), while at the same time using population data to compute the scarcity dimension.

3. Results

3.1. The LCZ Composition of Finnish Cities

Figure 1 provides a visual summary of the Finnish LCZ forms based on OSM data, together with the relative frequency and population density of each type. The Supplementary Material (Table S1) provides a more detailed summary of the average LCZ composition in Finnish cities and its variations from one city to another.

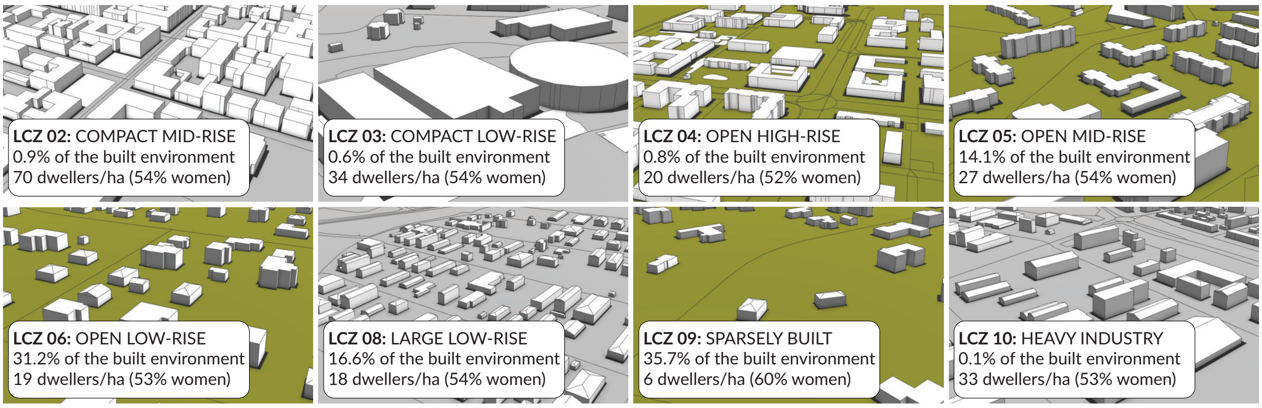

Figure 1. Visual summaries of the Finnish LCZs.

Compact high-rise neighbourhoods are not present in Finland; the densest LCZ types that are present in our sample are compact mid-rise and compact low-rise with a rather low share of the total urban area, about 1% each. Green neighbourhood morphologies are the dominant types; open low-rise neighbourhoods dominate the cities with 31.2% of the total areas, followed by open mid-rise (14.1%) and open high-rise (0.8%). The most extensive LCZ type in our sample of Finnish cities is sparsely built neighbourhoods, representing 35.7% of the total urban area. Large low-rises represent 16.6%, whereas there are traces of areas of "heavy industry" character in a few cities of the sample. These averages indicate the prevailing neighbourhood composition of the largest Finnish cities. Under this light, Finnish cities are dominated—physically—by green sparsely built and open low-rise neighbourhoods (67% in total), with a notable presence of green large low-rises and open mid-rises (31%). These relatively sparse, low, and green neighbourhoods collectively represent 98% of the total area of our sample of Finnish cities. Although there is variation from city to city, this pattern seems to hold as the general rule. We link this to sustainable spatial planning paradigms in Section 4.

3.2. Socio-Spatial Characteristics of Finnish LCZs

Table 1 (country-scale descriptive statistics), Table 2 (cross-city comparison), and Figure 2 (overview at varying spatial resolutions) provide a summary of the OSM data as interpreted from the urban commons standpoint (cf. Section 2.2 and Section 2.3). The two most populous urban commons types in terms of ownership and access, in a typical postcode of a Finnish city, are public nonexclusive (41 commons on average) and private nonexclusive (38 commons on average), therefore indicating a pervasiveness of commons that are accessible [illegible] ons follow, with private exclusive types being 26 on [illegible] ical urban postcode. In terms of scarcity, the prevailing [illegible] ypical postcode, which translates to a rather low rivalry [illegible] t at the neighbourhood scale, indicate an abundance of [illegible] could be interpreted as neighbourhoods with a certain [illegible] though the ground reality remains uncertain, given the [illegible] imal, these appear to come in the form of traditional [illegible] otable variability from one postcode to another across [illegible] imum and maximum numbers. Figure 2 indicates that [illegible] the size of the city but has to do also with the location [illegible] presumably denser areas exhibiting higher numbers of [illegible] es indicate a slight decline in the provision of commons [illegible] d Turku) to sparse and less populated (Rovaniemi and [illegible] se with both the absolute numbers of commons and [illegible] ip category. As expected, rivalry is higher in the larger [illegible] emi), but Kauniainen shows that rivalry in a sparse and [illegible] large cities, if the place is part of a metropolitan system [illegible] ea).

[illegible] ational scale.

Urban commons aspect	Total	Postcode mean	Postcode maximum	Postcode minimum
Private exclusive	22,377	26	1,107	0
Private nonexclusive	33,439	38	357	0
Public exclusive	7,212	8	190	0
Public nonexclusive	35,957	41	538	0
Rivalry (mean dwellers per commons)	—	134	8,165	0

Table 2. Comparison between the densest (Helsinki and Turku) and sparsest (Rovaniemi and Kauniainen) cities.

	Helsinki		Turku		Rovaniemi		Kauniainen	
Urban commons aspect	Total	Per hectare (ha)	Total	Per ha	Total	Per ha	Total	Per ha
Private exclusive	6,074	1	1,745	0.9	227	0.7	25	0.1
Private nonexclusive	6,001	1	1,675	0.9	215	0.6	134	0.3
Public exclusive	817	0.1	228	0.4	55	0.2	14	0.03
Public nonexclusive	7,472	1.2	1,348	0.7	144	0.4	75	0.2
Rivalry (mean dwellers per commons)	29	—	24	—	11	—	19	—
Demographic diversity								
Dwellers	534,092	—	139,287	—	28,825	—	10,124	—
% women	52.8	—	52.9	—	52.7	—	51.9	—

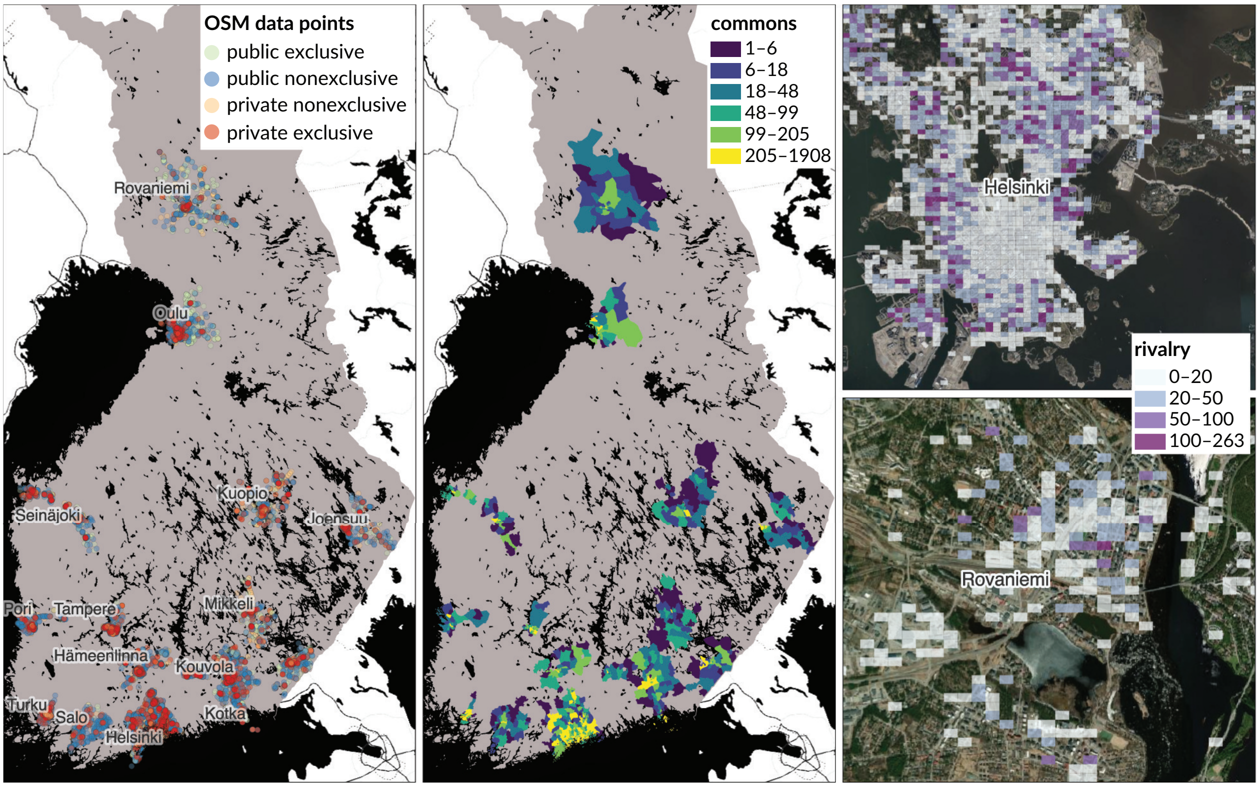

Figure 2. OSM data points categorised by ownership-access (left), total commons per postcode (centre), and rivalry (dwellers per commons) for the 1 ha LCZ pixels in Helsinki (right top) and Rovaniemi (right bottom). Note: The background maps is Stamen for the images in the left and central rows, and Bing Maps for those in the right row.

3.3. The Extended LCZs Typology for Finnish Cities

A more detailed view of urban socio-spatial patterns can be produced by associating the urban commons attributes of Section 3.2 with the LCZ patterns of Section 3.1. We further add basic demographic information for each LCZ in order to demonstrate the number of inhabitants in a typical LCZ type and the gender balance.

Each LCZ type is standardised to a one-hectare patch (100 by 100 metres). This is important, because—getting back to our introductory discussion—model output for a specific urban patch can be in this manner associated with urban fabrics found in reality, at least in terms of key social and physical parameters related to resilience. Table 3 provides an overview of the extended LCZ typology for Finnish cities, based on our sample of the 29 largest municipalities in Finland.

Altogether, we can maintain that Finnish cities seem to typically focus on sparse urban forms. It can be seen from Table 3 and Figure 1 that green sparsely built and open low-rise neighbourhoods dominate, which tend to offer to their dwellers urban commons of public and private nonexclusive character, with rather low rivalry potential as the number of commons tends to exceed both the number of buildings and dwellers in a neighbourhood. A few cities tend to have denser centres, and the typology shows that these offer high numbers of neighbourhood commons. Finnish cities appear to present a planning approach of mixing rural and urban land uses, with relatively good access to relatively abundant urban commons. In such a case, one could anticipate different risk and resilience patterns, depending on what type of LCZs are implemented. For instance, preferring an LCZ 02 type of residential development will mean different exposure (e.g., number of inhabitants) and vulnerability (e.g., urban commons processes) as opposed to following an LCZ 04 type.

There are no compact high-rise areas (LCZ 01) in Finnish cities. The compact mid-rise type (LCZ 02) is observed, with buildings of a maximum of nine floors theoretically, but fewer in practice. The largest continuous LCZ 02 area is located in Helsinki's city centre. From there, the city spreads sparsely outwards to the rest of the Finnish capital region. In most of the cities, LCZ 02 covers less than 2% of the built area (cf. Supplementary Material, Table S1), with the exception of Helsinki, Turku, and Tampere, which can be seen in the light of Münter and Volgmann's (2021) note that today the division between rural and urban tends to be blurry due to mixed land uses. Regions may appear polycentric with one dominating centre with global visibility such as Espoo, Vantaa, and Helsinki, with Helsinki being the most known and dominating centre. All cities except one in our sample contain LCZ 02 areas, usually near the city centre, and normally not large or contiguous. Open mid-rise (LCZ 05) neighbourhoods normally dominate near the city centres, which are typically characterised as compact mid-rise style and openly arranged. When moving toward the Finnish north and east, cities tend to be less dense with fewer LCZ 02 neighbourhoods, presumably due to lower population numbers compared to Helsinki and the south.

Alongside mid-rise neighbourhoods, Finnish cities have typically exceptionally low numbers of (under three floors) compact low-rises (LCZ 03), and a higher number of (more than 10 floors) open high-rises (LCZ 04). Both still cover less than 3% of the built area in every city (cf. Supplementary Material, Table S1). Helsinki is an exception, dominated by compact mid-rise (LCZ 02) and open mid-rise (LCZ 05) resulting in a comparatively more even skyline. Other cities have on average more LCZ 04 (0.81%) than LCZ 02 (0.74%), yet LCZ 05 is the most dominating neighbourhood type (13.47%) from the high and compact LCZ types. Thus, Finnish cities typically appear to have low-density neighbourhoods but also sparsely built high-rise neighbourhoods.

Heavy industry (LCZ 10) and large low-rise (LCZ 08) contain most of the commercial infrastructure. These are low-rise areas with buildings of a maximum of three floors, where the land is mostly paved and with minimal amounts of trees. In our sample, heavy industry (LCZ 10) is rarely contiguous and concentrated at one location of the city such that it would stand out as its own separate area. Only nine cities (out of the 29) had LCZ 10 pixels and they covered only 0.05% of our research area (Supplementary Material, Table S1), normally close to water and city centres. Only coastal municipalities exhibit LCZ 10. Despite its name, however, in Finland LCZ 10 does not exclusively contain heavy industry, but rather residential neighbourhoods with an "industrial feel" by building height and style, and amount of greenery. LCZ 08 is significantly more common than LCZ 10, as all cities in our sample contain between 5.35% and 28.86% of it. This LCZ contains airports, port areas, and commercial units and thus it is very common just outside the city centre.

The suburban landscape is dominated, in addition to large low-rise (LCZ 08), also by open low-rise (LCZ 06), and sparsely built (LCZ 09) neighbourhoods, which implies neighbourhoods with a maximum of three floors. LCZ 09 is the most common type in our sample (Supplementary Material, Table S1). In smaller municipalities, sparsely built neighbourhoods are the only ones found outside the city and its immediate area of influence, and even more so in the Finnish north and east. This LCZ type is evenly spread throughout these municipalities; for instance, in Rovaniemi and Joensuu, it covers more than 80% of the built area. On the other hand, Helsinki in the Finnish south exhibits less than 10% of sparsely built neighbourhoods, although open low-rise (LCZ 06) is the second most common type (27.19%) after open mid-rise (30.99%) (LCZ 05).

4. Discussion

We attempt now a shift toward a broader discussion on knowledge co-creation about sustainable and resilient cities and their co-design. On one hand, the socio-spatial extension of the LCZ typology provides a possible—though certainly not the only one—way to a dialogue between the global academic literature on sustainable cities and the empirical choices of Finnish planning practitioners. On the other hand, the typology helps to systematise and communicate the recommendations and role of CPSS in the co-design of future cities. We discuss these meta-concerns in Section 4.1 and Section 4.2 respectively, while also summarising the latter in the concluding section.

4.1. Finland's LCZ Patterns in the Context of Sustainable Spatial Planning Paradigms

While the LCZ typology does not exhaust the array of elements that researchers have been identifying as factors of urban sustainability, a socio-spatial extension of the typology adds to our capacity to treat a number of these concerns from a more integrative perspective. Through sustainable planning paradigms, we could argue that reading a city through a socio-spatial LCZ typology helps us understand the responses of Finnish urban planning practice to academic deliberations about the physical and social properties of sustainable cities. This juxtaposition between practice and theory has its merits, considering the long-held image of Nordic cities as leaders in sustainability—we could further argue that a dialogue between global sustainable cities literature and empirical choices in Finnish cities offers an additional angle to the co-creation of knowledge about spatial sustainability and resilience.

Academically, discussion about the physical characteristics of sustainable cities revolves around: (a) urban form and growth (Banister, 2008; Boschmann & Kwan, 2008; Burton, 2000; Burton et al., 1996; Dixon & Eames, 2014; Jabareen, 2006; Münter & Volgmann, 2021; Newman & Kenworthy, 1999; Pandit et al., 2017; Pendall et al., 2002; Taniguchi & Ikeda, 2005; Zhang et al., 2011), (b) land use (Echenique et al., 2012; Hautamäki et al., 2024; Houghton & Castillo-Salgado, 2019; Kühn, 2003; Masnavi, 2000; Medved et al., 2020; Santamouris, 2013; Saranko et al., 2020; Sera et al., 2019; Tang et al., 2007; Votsis, 2017), and

(c) transportation (Banister, 2008; Boschmann & Kwan, 2008; Krausse & Mardaljevic, 2005; Masnavi, 2000; Proske & Zdarilova, 2020; Williams, 2017). Researchers furthermore focus on the features of houses (Coutts et al., 2013; Estrada et al., 2017; Leal Filho et al., 2018; Luederitz et al., 2013; Medved et al., 2020; Sera et al., 2019; Yang et al., 2015), energy systems (e.g., Dixon & Eames, 2014; Jabareen, 2006; Kazimee, 2002), and environmental quality (e.g., Anguelovski et al., 2014, 2016; Kazimee, 2002; Luederitz et al., 2013; Uittenbroek et al., 2013). Community-related parameters are also discussed in the literature, more specifically the balance and mix between public and private space (Agyeman et al., 2013; Boydell & Searle, 2014; Kazimee, 2002), sociocultural diversity (Blok, 2020; Estrada et al., 2017; Jabareen, 2006; Kazimee, 2002; Pandit et al., 2017), education and inclusiveness (Anguelovski et al., 2016; Boschmann & Kwan, 2008; Dixon & Eames, 2014; Jabareen, 2006; Lanfranchi et al., 2018; Medved et al., 2020; Pandit et al., 2017; Puustinen, 2006; Sera et al., 2019), local economic development (Bagheri & Hjorth, 2007; Kazimee, 2002; Luederitz et al., 2013; Zhang et al., 2011), technology (Anguelovski et al., 2014; Caparros-Midwood et al., 2015; Hippi et al., 2020), and health and well-being (Banister, 2008; Dixon & Eames, 2014; Echenique et al., 2012; Houghton & Castillo-Salgado, 2019; Pugh et al., 2012; Rupp et al., 2015; Sera et al., 2019; Sörensen et al., 2016).

The empirical reality of Finnish spatial forms, when seen through the LCZ lens, appears to emphasize some of these elements while discouraging others, offering a distinctive Nordic interpretation of sustainable spatial planning: green and sparse, somewhat compact, and mixed but not comprehensively so built environments. In particular, the predominant production of residential spatial patterns in Finnish cities appears to favour open, mid/low-rise, and green forms, with compactness appearing only in a few large cities (Figure 1), which provides a Nordic view to the question of urban form occupying the literature. Furthermore, green and low-intensity LCZs are prevalent, which appears to be the preferred implementation of mixed land use and a strategy for connecting or separating features between city elements. On one hand, this links to additional literature about the benefits of urban vegetation (Hautamäki et al., 2024; Houghton & Castillo-Salgado, 2019; Houghton & Pugh et. al., 2012). On the other hand, there is limited implementation of the idea that mixed land use moves beyond mixing the rural with the urban, as it locates jobs, shops, and leisure facilities near each other (Jabareen, 2006). This is mostly found in compact LCZs with a variety of urban commons present (Table 2), whereas there is some presence of commercial and light industrial activities in large low-rise and residential-industrial LCZs. Interestingly, there are no comprehensively mixed land use LCZs—in Finland, it appears that mixing the rural into the urban is implemented separately from mixing diverse activities into the built environment.

4.2. Planning Paradigms and Computational Support for Co-Designing Sustainable Cities

Although participation has been central in imagining and negotiating sustainable pathways, co-design is paramount as it adds the experiential, tangible, and "artefactual" dimensions of sustainable urban futures (Candy & Dunagan, 2017; Hovorka & Peter, 2021). Design for sustainability is further considered to be a task of systemic embeddedness, that is integrating the object of design into the wider socio-technical system (Ceschin & Gaziulusoy, 2016). This invites a discussion about CPSS as co-design tools, that is, how are we to position a socio-spatial LCZ typology, as part of CPSS, in the co-design of urban futures? We develop this discussion by positioning co-design in the interplay between major urban planning paradigms (Taylor, 1998). We argue that a socio-spatial extension of the LCZ typology seeks to fulfil key concerns of co-design as a communicative planning paradigm, but at the same time, it reconnects this paradigm to long-standing physicalist and rationalist approaches, therefore facilitating the systems integration character of today's design for sustainability.

In particular, physical planning was envisioned as a top-down design-driven planning of the physical environment as opposed to social, economic, or political planning (Taylor, 1998, p. 13). As hinted in Section 1 and Section 2, the strong point of this paradigm is a systemic approach to designing sustainable built environments. A drawback of this approach is rigidness when it comes to understanding how various urban processes come together to form a functioning unity. Rationalist planning responded to this drawback by informing decisions with scientific knowledge about a city's processes. Rationalist planning reaches specific pre-determined goals (Taylor, 1998), based on research and scientific knowledge. The "rational" essentially amounts to instrumental rationality (mean-to-end) and reflects a search for the most effective and efficient solutions for pre-set goals, an approach that drew significantly from decision theory which, at that point, was outside the planning discipline. Another criticism of physical planning points to the lack of in-depth discussion of social and political processes, as well as its blindness to the underlying social reasons for urban change, which are fundamental in understanding not only the nature of social sustainability but also social aspects such as people's preparedness to react and accept changes towards sustainability. The communicative paradigm gives voice to the inhabitants of a city. This paradigm refers to planning practices based on shared interactive activities (Puustinen, 2006) and in practice, it is understood as participatory planning and co-design. In this paradigm, everyone affected by a plan should have the possibility to participate in decision-making (Healey, 2020; Taylor, 1998, p. 123) and understand the process and criteria. The planner's judgment is rarely free of preference and value and so public participation ensures that the interests of different groups of urban dwellers are considered in planning decisions.

The point is that co-design fulfils elements of all three major planning paradigms, although it is often erroneously seen as a communicative approach only. Historical shifts in planning paradigms indicate that overemphasising one aspect of urban planning has never been sufficient for achieving a well-faring sustainable urban society. From our perspective, a balanced combination of the elements of all three approaches is needed: (a) the physical paradigm provides the necessary safeguards of a well-designed functional built environment, (b) the rationalist approach brings decision theory and mean-to-end rationality into planning, (c) whereas the communicative paradigm accounts for the dwellers' interests.

So, the challenge to which this article contributes is to find a way to amend computer models of cities with bottom-up information, so that sound co-design—and not mere participation or loose co-creation—is achieved. Our choice was to expand the connection between the built environment and microclimate to include social indicators, overlaying an element of the communicative approach on a pre-existing model of physicalist-rationalist approaches. We implemented this by overlaying urban commons parameters on an existing LCZ typology in the major Finnish cities, testing how the addition of a communicative approach layer would look in practice in an empirical sample of cities. This invites further research and discussion into the advantages and limitations of incorporating information that is important for the communicative approach while acknowledging the capacity of computer urban models to work with the physical properties and scientific facts of built environments. We have also put forth a working hypothesis—which, too, invites further discussion—that urban commons information is one of the most promising instruments for reflecting elements of the communicative approach into other planning paradigms that are important but nevertheless suffer from the lack of bottom-up feedback. Some of the features that speak in favour of urban commons as such an instrument are:

- Urban commons depart from “dominance and control” (cf. Ståhle, 2006; Harvey, 1989) representations of urban space, offering instead an insight into representations of perceived and lived spaces (cf. Ståhle, 2006; Lefebvre, 1996); everyday uses of urban spaces naturally developing from the life flow of the dwellers.
- By doing so, urban commons information adds elements to computational co-design that are part of the climate resilience of the dwellers of urban spaces, rather than of only material urban spaces.
- Urban commons data provide relevant guidance about the more social aims of the UN Agenda 2030, particularly SDG 5 “gender equality,” SDG 10 “reduced inequalities,” and SDG 16 “peace, justice, and strong institutions.”

4.3. Limitations and Future Directions

The proposed new parameters introduce bottom-up informal activities of social groups. This is due to the feature of the corresponding source data by OSM, which maps a variety of citizen-reported social uses of buildings and urban spaces. However, urban commons are more than spatial activity and deal with several “invisible” cognitive and institutional processes, which we expect to have spatial expression, as Hillier and Hanson (2003) theorised. It is therefore fair to note that such data should be seen more precisely as indications of the presence or the potential for those social processes, rather than ultimate confirmation of them. Future work on this aspect can be the inclusion of additional parameters as a way to represent a broader cluster of such self-reported social activities, which can serve triangulation and interpretation robustness purposes. One example of such a parameter could be sub-daily mobility data so that estimating rivalry potential does not rest on static population statistics, but on the locations of citizens during their daily flow of activities. Another example could be sentiment data, which would illuminate part of the intentionality of citizens towards their spaces and therefore provide interpretative capacity for the types and distribution of urban commons that we observe in OSM data. A third example is to produce sub-types of urban commons data within the general private/public and exclusive/nonexclusive classification framework. This would allow a better understanding of the nature of social processes surrounding each point of interest. For instance, a community garden revolves around different socioecological processes than a library which is nowadays more related to digital commons and the knowledge commons.

Collecting such information by fieldwork (such as surveys, interviews, or notes) can further expand or replace the capacity of the OSM data to reach the underlying social processes. Such fieldwork is ideal for one location, but utilising community information found in OSM is more feasible for large-scale studies. Future research should address limitations surrounding the use of OSM data. Firstly, OSM information concerning the social uses of urban space is not a complete replacement for interviews or field observations. Information derived from OSM data should be rather seen as a proxy for fieldwork data that, although not providing the same depth of meaning, can produce information for a large number of locations in an automated manner. Secondly, although we use in this case OSM’s crowdsourced nature as an advantage in order to survey the social uses of urban space, researchers should be also aware of the inherent biases, pertaining for instance to the demographic groups that have volunteered geoinformation, as well as biased geographical representation. Although the literature indicates that OSM data are as a rule of equal quality to official geospatial information (Haklay, 2010), we expect that such biases are more pronounced in those parts of OSM that pertain to the meaning of urban space as opposed to its description as mere infrastructure. Lastly, the discussion throughout this article has included both sustainable spatial planning and climate-resilient cities as scopes, which may appear too broad. Although the LCZ typology is about climate resilience, this goal should be approached as a subset of the wider problem of spatial sustainability, from a socio-spatial perspective and also from a more theoretical sustainable spatial planning angle.

Lastly, although 8 out of the 10 LCZ types are represented in our sample, the majority of LCZs are low-intensity ones. This implies that the correlations between the socio-spatial parameters and LCZ types are less robust for the high-intensity types. Future research should address this issue by including a more balanced sample of LCZ types, which in the Nordic-Baltic context can be found, for instance, in Sweden, Denmark, and Estonia.

5. Conclusion: A Computational Co-Design Workflow

This article proposes a data-driven socio-spatial extension of the LCZ typology. Our approach relies on OSM data to retrieve urban commons information that, together with demographics, adds social content to the climate information of the original LCZ types. We can approach the extended typology as communicating what typical climate and social characteristics one expects to find in 10 built environment forms that we observe in the real world. We demonstrated this approach with data from the 29 largest Finnish municipalities at the 100-by-100-metre spatial resolution. We subsequently shifted the discussion to wider theoretical concerns. We posited that the typology is one way to detect a dialogue between the global academic literature on sustainable cities and the empirical choices of Finnish planning practitioners and positioned our work in the mutual interdependencies between three key planning paradigms.

Our underlying assumption is that CPSS ought to incorporate—or at least communicate—more of the bottom-up informal processes that contribute to societal resilience. This expansion in scope rests on their physicalist-rationalist merits but aligns them better with today's communicative turn in planning. By doing so, CPSS can provide a valuable co-design tool for urban sustainability. Our typology proposes to organise spatial sustainability alternatives by reference to real-world built environment types and what we know about their social and physical fabric. These design alternatives do need to be informed by scientific models of urban mechanisms so they can assess what aspects of the proposed designs are sustainable and what may be mere wishful thinking. But one must also be able to communicate scenarios that represent the lived environment in ways meaningful for a variety of stakeholders. Figure 3 illustrates this co-design proposition. It communicates that, if a co-design process starts with alternative plans, sketches, or ideas of sustainable built environments (Step 1), then at the minimum, a socio-spatial typology of real-world urban forms (Step 3) can be employed for the communication of those ideas through typified examples. For example, plan A suggests a mixture of LCZs X and Y, which, based on the empirical LCZ socio-spatial typology, represents N amount of people, provisions for such and such urban commons, and has known implications for the microclimate. Alternatively, an intermediate step can be introduced if more analytical depth is needed, where the proposed plans (Step 1) are assessed for their implications by CPSS (Step 2), before communicating the model outputs in a typology format (Step 3). Both workflows enable an iterative co-design process that is centred on a standardised and accessible language.

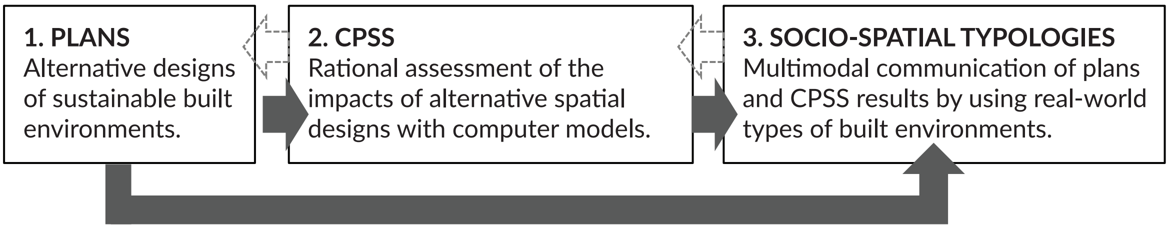

Figure 3. Co-design workflow that utilises CPSS (Step 2) and the socio-spatial LCZ typology (Step 3) as physicalist-rationalist (CPSS) and communicative (typology) planning tools.

Our approach is applicable at various spatial scales because it relies on point or fine-pixel data that can be aggregated to user-specific geometries (e.g., building blocks, postcodes, municipalities, or regions). The most relevant application is at scales between building blocks and neighbourhoods because both the LCZ typology and the urban commons data aim to communicate something meaningful at finer scales of human activity. This approach can be applied worldwide, because it relies on extracting globally and freely available OSM data to map the urban commons components, whereas open-source algorithms can construct the LCZ typology from OSM. Our approach has the potential for broader applications in urban planning. The fusion of formal built environment with informal uses and representations of urban space can facilitate a more comprehensive and accurate mapping of social vulnerability to climate and weather impacts because such data offer integrated insights into the activities and social interactions of people, and where they occur. This can further help to develop better risk and impact assessment models. Lastly, our approach can help to develop tools within the communicative and participatory strands of urban planning. Visual communication of existing and envisioned built environments, which is moreover semantically enriched with subjective representations of urban space, can serve as a common and more nuanced language that engages stakeholders around the kinds of daily life they envision, in which types of urban spaces, and with what microclimatic implications. Borrowing from Jakobson's model of communication (Hébert, 2020) and our current understanding of multimodal communication (Forceville, 2020), our typology enables the communication of messages about urban futures that are both relevant to a variety of audiences and embedded into their pragmatic contexts. It therefore embeds CPSS—as language in addition to a co-design tool—into the broader array of sociocultural functions that languages seek to perform.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The algorithm and retrieved OSM data are available online at https://doi.org/10.5281/zenodo.14946124

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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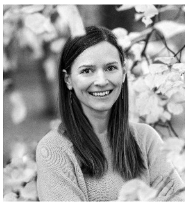
About the Authors

Athanasios Votsis is an assistant professor of sustainability of complex adaptive systems at the University of Twente. He is an urban and regional planner, geographer, and semiotician with an interest in computational, cultural, and cognitive angles to spatial sustainability, climate adaptation, and human-environment interaction.



Vuokko Heikinheimo is a senior researcher at the Finnish Environment Institute and holds a PhD from the Digital Geography Lab, at the University of Helsinki. She specializes in geographic information science with a focus on urban sustainability. Her research interests include land use change, accessibility, and open spatial data.

Milla Mikkola is a consultant at Ramboll Finland in the Sustainable Urban Development department. She is a geographer in regional planning and politics (University of Oulu). Mikkola specializes in climate-resilient urban planning and spatial data analysis. Before Ramboll, she was a researcher at the Finnish Meteorological Institute, focusing on sustainable planning paradigms.

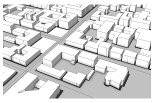
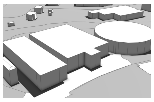
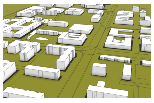
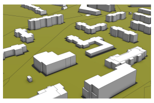
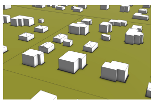
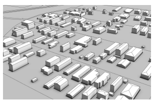
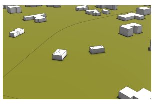
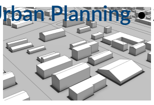
Dina Babushkina is an assistant professor in philosophy of technology & society at the University of Twente. She is working on a broad range of topics on responsible and human technology, as well as on normative ethics, moral psychology, and the history of ideas.

Aija Staffans is an architect and works as a senior research fellow at Aalto University, Finland. Her research interest is in urban planning and design, especially in collaborative processes and knowledge integration. She is a pioneer in developing participatory methods and digitally supported platforms for land use planning.

Tiina Merikoski has 15+ years of experience in urban planning and development, both as a researcher and consultant. Her expertise is in participatory and collaborative planning. As a landscape architect, she promotes urban green for its multifunctional benefits and nature-based solutions for playing a key role in achieving climate goals.

Stan Geertman is emeritus professor of urban and regional planning at Utrecht University in the Netherlands. He has published widely in scientific and practice-oriented journals and has published a range of (editorial) books. He is a member of the editorial board of several scientific journals (e.g., CEUS). He has been a member of a range of international conference organizations (EGIS, JECC, AGILE, and DDSS) and was chair of the Board of Directors of CUPUM (Computational Urban Planning and Urban Management) during the past 10 years. His research interests include planning and decision support systems (PSS/DSS), digital planning, sustainable urbanization, and planning theory and its implications for practice.

Table 3. A typology of Finnish neighbourhoods, per LCZ, urban commons, and demographics.

	Built-up morphology		Urban commons and demographics		
	3D shape [(a)]	Ecology [(a)]	Urban commons types [(b)]	Urban commons rivalry [(c)]	Demographics [(d)]
02 Compact mid-rise 	Tightly packed buildings 3–9 floors	Few/no trees and little/no green space	0.55 0.23 0.02 0.19	3 8 100 10	70 (54%)
03 Compact low-rise 	Tightly packed buildings 1–3 floors	Few/no trees and little/no green space	0.35 0.29 0.04 0.31	2 3 24 3	34 (54%)
04 Open high-rise 	Openly arranged buildings of 10 + floors	Abundance of trees and pervious cover (low plants)	0.14 0.40 0.04 0.41	4 1 14 1	20 (52%)
05 Open mid-rise 	Openly arranged buildings of 3–9 floors	Abundance of trees and pervious cover (low plants)	0.20 0.40 0.06 0.34	4 2 13 2	27 (54%)
06 Open low-rise 	Openly arranged buildings of 1–3 floors	Abundance of trees and pervious cover (low plants)	0.12 0.41 0.08 0.37	4 1 6 1	19 (53%)
08 Large low-rise 	Large and openly arranged buildings of 1–3 floors	Few/no trees and land mostly paved	0.33 0.34 0.04 0.24	1 1 13 2	18 (54%)
09 Sparsely built 	Sparse arrangement of small- or mid-sized buildings	Natural setting and abundance of pervious cover	0.11 0.34 0.08 0.48	1 0 2 0	6 (60%)
10 Heavy industry 	Low- or mid-rise industrial structures	Few/no trees and land mostly paved or	0.63 0.18 0.02 0.18	1 5 47 5	33 (53%)