A quantitative analysis of interstitial spaces to improve climate change resilience in Southern African cities

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Abstract

Globally urbanization is accelerating, especially within developing countries. This often results in vulnerable urban conditions with limited adaptive capacity to respond to climate change-induced hazards. In response, employing innovative solutions that lever existing unused and underutilized interstitial spaces within the urban fabric for climate change adaptation and mitigation purposes are needed. Essential to this strategy is a better understanding of the quantity and type of potentially available interstitial space. Using a mixed-method approach, this paper analysed the spatial and material condition of unused and underutilized interstitial spaces within a Southern African city. This study organizes these interstitial spaces according to programme, zoning, access, spatial definition, microclimatic characteristics and material use. It undertakes a quantitative assessment identifying seven specific interstitial space types, found in the total study area. Underutilized parking spaces and rooftop spaces are identified as the most prevalent space types with significant climate change adaptation and mitigation potential if appropriately retrofitted. Retrofitting these spaces are relatively effortless, and can ultimately improve the climate change resilience of these cities.

Keywords: Climate change; adaptation; mitigation; urban voids; urban morphology

1. Introduction

Cities are continuously subjected to climate change-induced disturbances and variances, yet are often unable to harness or accommodate the press and pulse disturbances affecting them. While these disturbances might be caused by external factors, internal disturbances and their resultant vulnerabilities can also be precipitated by the urban spatial structure itself (Seto & Shepherd, 2009). As a result, internal disturbances are often caused by the inability of established urban environments to adapt to climate change impacts. Using local knowledge to uncover the latent potential of the urban structure enables systemic structural changes that can be considered as steps towards facilitating climate transformation as proposed by Pelling, O' Brien, and Matyas (2015).

The IPCC propose using of both mitigation and adaptation to respond to adverse climate change-driven impacts in both urban and rural areas (IPCC, 2014). While climate change mitigation is important, implementing adaptation measures to respond to these adverse impacts are becoming urgent. As the global greenhouse gas concentration crossed the 400 ppm CO_{2eq} mark in 2015 representative concentration pathway 4.5 forecasted conditions can be assumed (IPCC, 2014; Van Vuuren et al., 2011). Preparing for these long term, permanent changes requires undertaking climate change adaptation measures within our cities (IPCC, 2014).

Sub-Saharan cities are often subject to developmental pressures as well as climate change impacts and need to balance their response strategies with limited financial resources, skills, and capacity (Kithiia, 2011; Roberts, 2010). While large portions of these cities are informal, they also comprise of formalized neighbourhoods that are subject to similar constraints but has the potential to follow alternative methods of addressing climate change. In-situ strategies that promote compact infill development can increase urban population densities and programmatic intensities of existing neighbourhoods (Faling, 2012). Such infill strategies can include retrofitting existing unused and underutilized interstitial spaces to implement climate change adaptation and mitigation strategies, whilst still accommodating the resident populations in these neighbourhoods.

In order to enable the use of these interstitial spaces, the spatial and material characteristics, ownership and land-use rights, retrofitting costs and benefits, and potential economic and social benefits must be uncovered. This study focuses on the first step, i.e. determining the quantity and types of suitable interstitial spaces available and their spatial and material characteristics. As research objective, the study aimed to quantify the spatial potential of existing unused and underutilized interstitial spaces in a South African city to enable small scale climate change mitigation and adaptation strategies. It uses a multi-participant geo-referenced method to collate the observations and perspectives of built environment professionals into a collective reading of the urban whole. This enabled the development of a spatial taxonomy of unused and underutilized interstitial spaces as well as the quantification of the available space revealing the adaptation and mitigation potential of the study area.

As users often appropriate spaces differently from the original design intent, this study presented a method of constructing a holistic overview of the neighbourhood using a ground-level analysis procedure to uncover small scale opportunities that can have cascading catalytic effects if collectively retrofitted. From this overview, top-down policies can be considered and aligned with the existing urban context.

This paper is structured to firstly consider the existing formalized Southern African urban conditions as research context and the nature of interstitial spaces. It then discusses the specific South African study area after which it elaborates on the method used to uncover these potential spaces. Finally, through the analysis of unused and underutilized spaces of a neighbourhood in Tshwane, various types of spaces and their retrofitting potential are discussed.

2. Theoretical background and argument

2.1. Urban development in Southern Africa

The indiscriminate impact of climate change will affect multiple sectors and demographic groups regardless of their contribution to this global problem. While Africa needs to brace itself for a series of severe climate change induced impacts (IPCC, 2014), it is also forecasted as one of the fastest urbanizing continents (United Nations, 2015). This highlights the need for African countries to accommodate both growing urban populations and navigate the impact of changing climatic conditions.

The informal nature of sub-Saharan cities has to date received much attention (Dodman, Leck, Rusca, & Colenbrander, 2017; Le Roux, Mans, Huyssteen, & van Niekerk, 2017), noting significant development taking place on or beyond the ill-defined urban edge (Chobokoane & Horn, 2015). While the need to address informal urbanism cannot be disputed, Southern African cities also comprise of older formalized neighbourhoods that are also changing rapidly to accommodate an urbanizing population (Mabin, Butcher, & Bloch, 2013), yet less attention is given to these existing Southern African urban conditions.

As established urban areas these existing neighbourhoods are often ignored as they do not present urgent crises to human wellbeing and have the capacity to provide basic services (Sartorius & Sartorius, 2016). Yet, these neighbourhoods are subject to slow press disturbances and contribute to adverse impacts beyond their periphery. As African cities need to balance climate change adaptation and mitigation initiatives with the associated developmental pressures due to rapid urbanization and the lack of infrastructure, funding to address all these needs is often limited (Kithiia, 2011; Lwasa, 2010; Roberts, 2010). While we agree that these formalized existing neighbourhoods do not qualify for additional development funding, alternative methods to retrofit the existing neighbourhoods through a network of small scale public or private initiatives are needed.

Considering the rapid changes in African urban environments and the risks associated with them, undertaking bottom-up small scale experiments to gain momentum presents a viable strategy (Fraser et al., 2017). Bottom-up strategies can therefore potentially be more effective to function in these changing urban conditions (Souza et al., 2015). Using the existing urban structure itself and retrofitting it to promote infill development can enable neighbourhoods as a whole to respond to climate change (Chobokoane & Horn, 2015; Faling, 2012). This approach calls for the use of in-situ, contextual changes, that can be considered as incremental adaptation (Ziervogel, Cowen, & Ziniades, 2016), yet adapting the existing urban structure addresses spatial conditions that drives climate vulnerability (Pelling et al., 2015). Analysing, defining and using the existing unused and underutilized interstitial spaces identifies such opportunities.

2.2. The diverse nature of interstitial spaces

Urban interstitial spaces are often defined as anti-space, latent space, or dormant spaces. This indeterminacy in spatial definition results in a vaguely defined spatial condition. While the spatial presence of interstitial spaces can be detected within the urban environment, this lack of formal definition allows it to slip into obscurity.

Exploring the potential of interstitial spaces is not new. As early as 1910, Patrick Geddes argued for the use of vacant, unused spaces within the city to improve its socio-economic conditions (Crowe & Foley, 2017; Meller, 1990). Using surveying techniques, Geddes developed the concept of conservation surgery to retain the existing urban fabric during urban redevelopment projects (Welter, 2002). Walter Benjamin's work on liminality, porosity and the interpenetration of spaces, presented the "inexhaustible potential" of the hidden edge conditions (resulting in and from interstitial spaces) to enable alternative heterogeneous uses (Benjamin, 2010; Sankalia, 2010).

Kevin Lynch (1960) identified the edge definition as one of five critical urban elements that convey urban morphology, legibility and imageability – the edge condition being specifically important in promoting or inhibiting unused or underutilized space to develop. Jane Jacobs (1961) furthers the argument, identifying the notion of border vacuums which is often the result of monofunctional, unplanned and inappropriately scaled developments. Both these authors identified such spatial conditions as anti-urban spatial elements with detrimental effects on the urban character.

Roger Trancik (1986) is one of the first theorists to formally define interstitial spaces within the modern urban environment. He coined the term anti-space arguing that cities contain a number of anti-spaces due to modern planning practices subject to strict zoning regulations, land-use policies and vehicle orientated designs (Trancik, 1986). These left-over, underutilized spaces are therefore often outcomes of other developments or urban interventions (Tonnelat, 2008) and manifest as left-over, unused or abandoned spaces (Trancik, 1986).

These spaces need not be considered as undesirable. Jim (2004) argues that interstitial spaces hold the potential to integrate green infrastructure within the urban environment. In dense cities, he calls for the identification of open spaces to establish vegetation in order to ameliorate the urban heat island effect. While Jim (2004) points out the value that interstitial spaces hold for the city, considering these spaces beyond their open space potential is important.

Interstitial spaces can transcend the physical parameters and be interpreted by how they are used and reused. Tonnelat (2008) argues that interstitial spaces are specifically 'foreign matter' between one spatial condition and another, resulting in spaces that are out of place. These spaces function contrary to surrounding or intended programmes, and are divergent in spatial articulation through material use and scale, enabling alternative users to inhabit similar urban contexts using new spatial arrangements.

Van Eeghem, Steel, Verschelden, and Dekeyrel (2011) further this argument by defining interstitial spaces as cracks within the urban environment resulting from an oversight of formal urban design and zoning. Citing Weeldhou, they propose that these are the 'manifestations of the inoperative city' (Weeldhou, 1998 in Van Eeghem et al., 2011) – the residue of inappropriate designs. This means that interstitial spaces are often either accidentally or purposefully hidden. It can be argued though that these spaces actually satisfy the unmet needs of the city or citizen – resulting in the users or citizens identifying these interstitial spaces as useful and valuable, while city planners consider these empty left-over spaces as wasteful (Tonnelat, 2008). These interstitial spaces are therefore often kept 'invisible' by users in order to retain their existence and use.

In the South African context, interstitial spaces formed part of the apartheid city planning strategies to separate different racial groups. As a result, a series of buffer zones were created between neighbourhoods, not only isolating certain neighbourhoods but also hiding them and limiting their legitimacy as urban centres (Guillaume & Houssay-holzschlich, 2002; Huyssteen, Biermann, Naude, & Le Roux, 2009). While many documented these spatial conditions on large macro urban scales, studies by Lemanski (2006) and Landman (2016) also reveal the existence of such spaces at smaller scales permeating into Post-Apartheid city planning. Neighbourhoods, public places and civic buildings are often designed as defensible spaces using buffer zones, security measures, and restrictive movement-planning as control measures, resulting in unused, isolated, interstitial spaces along their perimeters (Landman, 2016; Lemanski, 2006). Interstitial spaces are therefore found on different scales and perpetuated through measures of control. This study argues that these smaller methods of separation are located throughout the formalized urban contexts in South Africa. As revealed in the work of Doron (2000) and Galt, Gray, and Hurley (2014) finding opportunities for imaginative use of these spaces can enable the implementation of alternative uses – in this case climate adaptation and mitigation strategies.

2.3. The potential of retrofitting interstitial spaces to develop climate change resilient cities

Identifying and using these unused and underutilized interstitial space networks present the potential to insert small scale climate change adaptation and mitigation strategies within the city, whilst retaining its overall functionality (Houghton, Foth, & Miller, 2015). To build the adaptive capacity of cities require holistic integrated processes (Roberts, 2010) that identify both top-down strategies, and bottom-up social and spatial transformation approaches. Using smaller scaled in-situ projects to prepare cities for climate change-induced impacts (Souza et al., 2015), can follow bottom-up processes but have specific spatial requirements. Understanding the spatial structure of cities, and the leverage potential it holds is important to improve the efficiency of these bottom-up strategies.

While the varied scale of cities allow for diverse response strategies ranging from larger landscape networks, social-technical regimes to specific niches for experimentation (Castán Broto & Bulkeley, 2013), these smaller interstitial spaces and transforming them using eco-acupuncture methods, as proposed by Ryan (2013), play an important role within the larger urban network. It can provide extensive spatial coverage within existing cities to contribute to fundamental systemic change (Mapfumo et al., 2017). In addition, these interconnected spatial opportunities can contribute to realizing a series of catalytic projects stimulating cascading impacts on the city (Ryan, 2013).

2.4. Existing urban context and its associated vulnerabilities

The research was undertaken in Hatfield, an older, rapidly changing neighbourhood in Tshwane. The City of Tshwane is one of South Africa's eight largest metropoles and is a mainly low density, sprawling city. Build upon modern urban planning ideals, the city and its neighbourhoods present a typical older urban form as found in a number of countries in sub-Saharan Africa.

The original city structure was laid out on an exceptionally large grid (240 × 120 m). While this has led to the initial innovative use of the large stand, modern urban planning approaches, unfortunately, left these city blocks with large open, undefined spaces between the buildings. The subsequent implementation of extensive security measures such as boundary walls and fences have left these spaces vacant, unkept, and inaccessible.

As a typical economic hub in a polycentric city, Hatfield followed the classic anti-urban development strategies identified by Trancik (1986). Hatfield developed as a simple neighbourhood adjacent to the University of Pretoria campus. With the influx of student numbers and the construction of an intercity high-speed train connecting Tshwane and Johannesburg, the neighbourhood experienced significant economic growth. Currently it has a variety of building stock spanning from both low scale residential typologies, used for housing and offices, to high-density monofunctional student accommodation. It has a transient student community and nine-to-five office worker population. The development neglected open – and public space provision and is primarily vehicular-orientated. As a result of increasing security concerns, most buildings have isolated themselves to limit access for the general public, segregating themselves from the public realm.

In terms of the local vulnerabilities, the IPCC (2014) reports that South African cities will be affected in a number of ways. Firstly, temperature increases expected for the South African interior will be 1.5–2 times the global average (Ziervogel et al., 2014). This will be further intensified due to poor urban and building design driving the local urban heat island (UHI) impacts (Peng et al., 2012). A study by Monana (2012) documenting the UHI impact in Tshwane concluded that areas with little vegetation and bare soil are typically subject to extensive UHI impacts. Amongst other impacts, this further increases the impact of extreme weather events, resulting in higher morbidity and mortality, and energy use (Seto & Shepherd, 2009; Van Der Hoeven & Wandl, 2015).

Studies by Mason, Waylen, Mimmack, Rajaratnam, and Harrison (1999) and Shongwe et al. (2009) forecasts warmer, dryer winter conditions, as well as fewer rain days during the summer rainfall season with lowered precipitation rates. This will lead to increase vulnerability to local precipitation driven flooding (Douglas et al., 2008) and a loss in water security (Dos Santos et al., 2017).

The increase in temperatures and loss in water security will have a cascading effect on food security. Frayne, Moser, and Ziervogel (2012) argues that climate change will affect local food networks through lowered food supplies due to crop failures, shorter shelf lives for certain food types, limited access to food due to changing socio-economic conditions, and lower fluid intake.

This neighbourhood, as other cities in South Africa, will be subject to water and food insecurity as well as increased extreme temperatures that in turn will have further social and economic impacts. The material and spatial conditions of the urban environment can both ameliorate or further exacerbate the impacts. This study intends to define and quantify these unused and underutilized interstitial spaces in the suburb of Hatfield as a first step to better understand the climate change adaptation and mitigation potential that such spaces present.

2.5. Climate change adaptation and mitigation retrofitting potential of interstitial spaces

While many studies have considered vacant lots within the urban context (Kim, Miller, & Nowak, 2018; Németh & Langhorst, 2014), this study rather extended the scope to consider underperforming spaces or urban voids as noted by Bhaskaran (2018) to identify spaces that can facilitate positive and dynamic relationships with the adjacent context. As a result, it extends the analyses to underperforming spaces with retrofitting potential, revealing spatial conditions, as advocated by Carter (2011) and Kithiia (2011), that can align high-level climate change mitigation and adaptation strategies with the existing local spatial conditions to enable implementation thereof. As argued by Kithiia (2011), national policies must be complemented by local strategies to enable deep and quick leverage potential within the local urban conditions.

These local latent interstitial spaces present the spatial and material characteristics that increase the local urban heat island impacts and water insecurity, yet concurrently these spaces present the potential to accommodate climate change adaptation strategies that address excessive heat, water scarcity, energy supply and food insecurity (IPCC, 2014). By using the network leverage potential through urban infill strategies, extensive climate change adaptation strategies can be undertaken (Faling, 2012; Jim, 2004). These include using the existing hard surfaces to capture rainwater for purification and long term storage, and adding vegetation or changing the albedo factors of the highly exposed surfaces limiting thermal energy gain. In addition these spaces that are highly exposed to insolation also present opportunities for photovoltaic energy generation. Implementing these strategies on smaller scales ultimately improves the individual adaptive capacity (Lwasa, 2010).

3. Research method and context

Similar to the work of Kim et al. (2018) this study used a multi-stage, mixed-method approach to document and analyse the urban environment. A group of 21 architecture, landscape architecture and interior architecture students were used as participants to document and analyse the Hatfield neighbourhood. The study area covered an area of 1.8 by 1.2 km and the study boundaries were agreed upon beforehand. It included the university campus, the larger Hatfield neighbourhood and a smaller area controlled by the Hatfield City Improvement District.

A two-phased procedure was followed that included a desktop analysis that used aerial photographs, cadastral data and data from previous transect walks. This ensured an overall spatial understanding of the context and identified potential spaces to document. The second phase included transect walks and observational analyses. This allowed the participants to confirm and document the spaces as well as identify additional spaces that were otherwise missed during the desktop study. The observations were photographically recorded and an open-source online survey tool, EpiCollect 5, captured and geolocated the data. The survey required that students document the current use or disuse of spaces, their edge definition, microclimate, surrounding urban context, and site aspect. Further data such as material use and vegetation cover were deduced from the photographic analysis. The undefined nature of these spaces required the use of this collaborative mixed-method procedure to document the participants' interpretations of the city and collate them for analysis purposes.

The final data sets were collected, verified and overlaid, and identified 63 spaces for analysis. These were interpreted using descriptive statistical methods as well as spatial analyses using an online GIS visualization tool, Mapable®. From the spatial data, both the proportionate area coverage and frequency of incidence were analysed. As concluding stage, spatial characteristics were organized in an interstitial space matrix allowing for further analysis.

This method used a multi-participant reading of the city without predetermined notions of typological classification. This allowed the analysis to go beyond the conventional cadastral land-use definitions to present an alternative, collated observational interpretation of the city. In contrast to current studies that assume the current land-use classification (Kim et al., 2018; Németh & Langhorst, 2014), this method moves towards developing a taxonomy for vaguely defined spatial conditions.

Due to the fine-grained, cross-classification analysis of these spaces, this method allows for a collaborative sense-making process to reveal the current realities within the urban environment, with results that are far richer than that provided by only satellite and cadastral data. The spatial and material findings provided by this process allowed a rich overview of the existing context to be developed which can further inform top-down process and allow for the better alignment of bottom-up strategies, both amongst each other and with top-down policies (Figure 1). The use of open-source, flexible and mobile technology allows the implementation of this method in a variety of

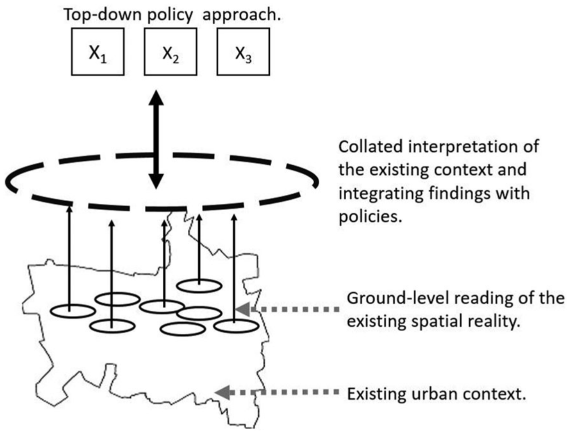

Figure 1. Ground-level analysis to develop an overview of the context and inform top-down coordination.

contexts – specifically developing cities. While this study used students from the built environment disciplines, the method can be used by other groups. The value lies in the iterative and collaborative sense-making and interpretation of space.

4. Findings and discussion

4.1 Space type overview

The study defined and quantified the unused and underutilized interstitial spaces that are often considered wasteful and useless to the city, but which presents opportunities to be retrofitted and converted if their potential value are considered, as argued by Van Eeghem et al. (2011).

The various spaces were considered along with two parameters: frequency of incidence, and potential space impact. These parameters serve as indicators in terms of their leverage potential to promote infill development using interstitial spaces and increasing the programme intensity by implementing a network of smaller projects to upgrade the existing urban assets (Faling, 2012). In terms of total area coverage, the documented spaces amount to 7% (155,077 m^2) of the total study area (2,130,000 m^2). Surprisingly this resulted in being significantly less than what was originally assumed available and revealed in other studies by Kim et al. (2018) and Németh and Langhorst (2014).

The documented interstitial spaces can be categorized as underutilized parking spaces, rooftop spaces, in-between spaces, neglected spaces, un-used open plots, servitude spaces, and other or interior spaces. The frequency of incidence and potential spatial impact of each type are presented in Table 1. The inventory revealed that underutilized parking and rooftop spaces contribute the largest number of spaces (72% of the total, $n = 49$) and total area potential (67% of the total area coverage, 97,319 m^2).

The study revealed that the location and urban morphology of the context have a significant impact on the spatial nature of the interstitial spaces. In Figure 2, it is clear firstly, that the spaces are located in large scale civic, education or commercially programmed areas. Although the smaller grained residential areas contain interstitial spaces, these were deemed unfeasible for retrofitting and modification on an individual project basis. This indicated a relationship between the interstitial spaces and immediate context in terms of how it is read and used. Secondly, large scale developments start manifesting inefficient space-use and opportunities for small scale urban intensification, allowing therefore for multiple scales of networks and built projects that are critical within these monoscalar environments (Castán Broto & Bulkeley, 2013).

4.2. Spatial parameters and characteristics

The analysis of the various space types considered a series of morphological and spatial characteristics. This required the deductive analysis of both the spaces themselves and the adjacent contexts, specifically considering the building programmes, ownership and neighbouring building heights. The spatial articulation of the interstitial spaces were considered in terms of edge definition, orientation of the sites and the sky view factor (SVF). Finally, the material and vegetation cover within these spaces were analysed. This process of unpacking these parameters exposes the often hidden potential of these interstitial spaces within the urban context (Tonnelat, 2008).

As initial stage, the solar exposure and contextual character of the various spaces were considered. The study documented the degree of edge definition that encloses the spaces as a means to analyse access to these spaces and solar irradiance (Figure 3). The analysis revealed that only 16% ($n = 11$) of all the spaces have three or more containing edges. In terms of completely open undefined spaces with few physical edge conditions, 55% ($n = 37$) of all the spaces present this spatial condition. These open spaces generally comprise of rooftop spaces, and the undefined edge conditions, therefore, do not denote accessibility. Excluding rooftop spaces from the analysis still resulted in 69% ($n = 24$ of total of 35) of the spaces having a high degree of accessibility and solar exposure.

SVF refers to the total proportion of visible sky that is open to the space considered. It has both an impact on the solar

Table 1. Comparison of interstitial space types, frequency of incidence and total area.

Space type	Number of incidence	Percentage of incidence	Total area covered (m^2)	Percentage of area covered
Underutilized parking spaces	16	24	55,793	36
Roof spaces	32	48	47,788	31
In-between spaces	8	12	10,528	7
Neglected spaces	6	9	3917	3
Open plots	2	3	10,423	7
Servitude	1	1	601	0
Other or interior spaces	2	3	26,028	17

Notes: Percentage of incidence refers to the proportion of the total number of spaces documented. Percentage of area covered refers to the proportion of the total area of these spaces.

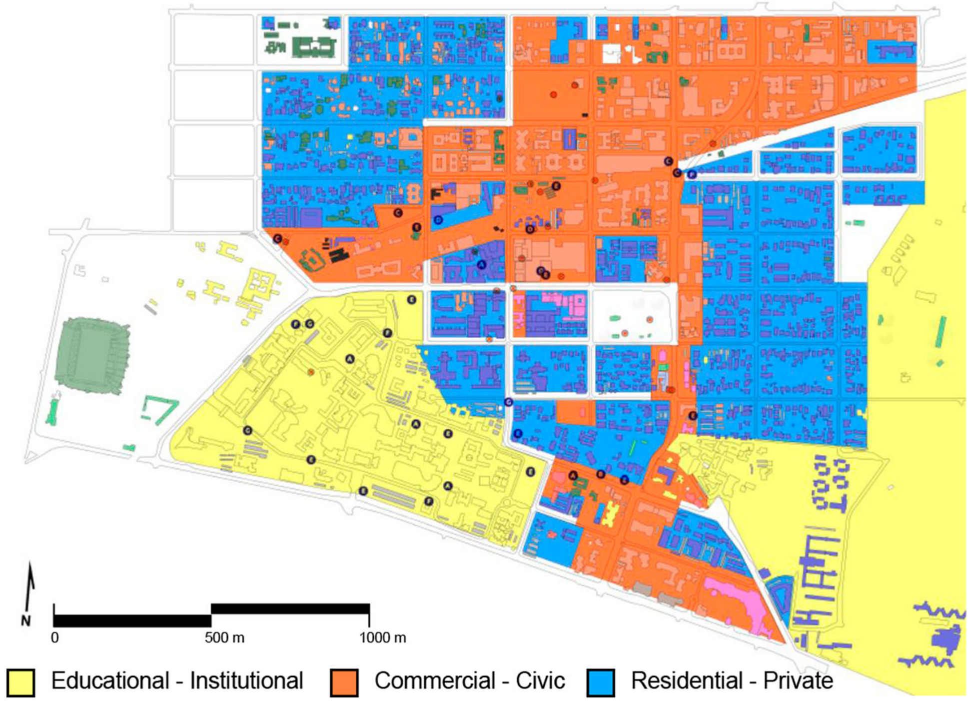

Figure 2. Location of interstitial spaces within Hatfield, Tshwane.

irradiance levels received on-site and the ability of the space to re-radiate heat back into the atmosphere during cooling periods (Kleerekoper, Esch, & Baldiri, 2012). This is specifically important due to the climate change-induced temperature increases forecasted for Southern Africa (Ziervogel et al., 2014). In our study, 88% ($n = 40$ (SVF – 1) + 19 (SVF – 0.75)) of the spaces have an SVF of 75% or more (Figure 3). Underutilized parking spaces and rooftop spaces contribute mainly to this exposed spatial condition (81%).

A further consideration into the solar exposure examined the orientation of the sites themselves and their relation to the tallest building within the immediate context. The study determined that 64% ($n = 43$) of the spaces have an east–west orientation, while only 19% ($n = 13$) has a north–south orientation and 16% ($n = 11$) exhibit omni-directional spatial conditions (Figure 3).

Overshadowing due to the surrounding built fabric occurs on varied scales. A large portion (48%) of all the spaces are roof spaces that experience little to no overshadowing. The remaining space types are impacted on various levels, with 16% ($n = 11$) experiencing significant overshadowing during the winter period, while a further 16% (East: $n = 4$; West: $n = 7$) experiences overshadowing at the start and end of the day. Isolating the cases with optimal east–west orientation and considering the overshadowing of these spaces determined that 21% ($n = 9$) of those sites are located to the south of taller

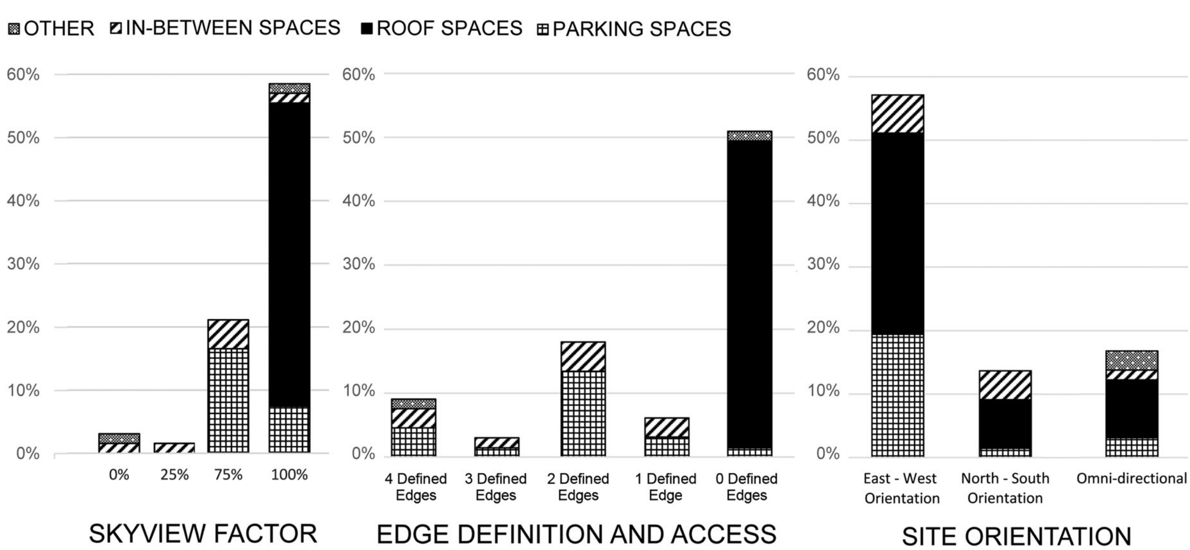

Figure 3. Morphological characteristics of predominant interstitial spaces.

structures and will experience overshadowing at certain times of the year. The remaining 79% ($n = 31$) encounters very little overshadowing.

The analysed interstitial spaces all embody multiple levels of vegetation cover. In terms of the total area coverage, 63% of the total potential spatial impact has no vegetation with extensive impermeable surfaces. In comparison, 24% of the total area coverage has little scattered vegetation with extensive impermeable surfaces, only 7% of the total area coverage shows extensive tree coverage with the remaining 6% introducing permeable surfaces and extensive planting. As the predominant space types, roof spaces presently accommodate no vegetation, while parking areas contain little vegetation. While this is primarily informed by the function of these spaces, it also manifests as ill-considered spatial responses that perpetuate inappropriate city forms (Chobokoane & Horn, 2015).

Considering the solar exposure of these unused and underutilized interstitial spaces reveal both significant opportunities and concerns. An overwhelming number of spaces, 80% ($n = 53$), have limited overshadowing and high levels of solar irradiation exposure. Similarly, 83% ($n = 57$) of these spaces are covered with little to no vegetation and articulated with impermeable surfaces with high thermal capacities and low albedo rates. These spaces therefore present significant leverage potential to address the local urban heat island impacts.

5. Conclusion

This study undertook a quantitative analysis of unused and underutilized interstitial spaces within a formalized yet developing neighbourhood in a Southern African polycentric city. The purpose was to quantify spatial opportunities to implement climate change adaptation and mitigation strategies in the City of Tshwane using unused and underutilized interstitial spaces. Using a mixed-method process with adaptable, mobile technologies and multiple participants allowed for a more reliable method to determine and collate generally vague and undefined spatial conditions that straddle multiple spatial conditions. This research process allowed for various interpretations of the city to be documented and analysed to develop robust geolocated data on the existing unused and underutilized interstitial spaces. The use of portable technology and multiple individuals is specifically relevant for developing countries where little geospatial data is available.

The analysis of unused and underutilized interstitial spaces confirms that the vulnerability of cities to associated climate change impacts is often ingrained within the urban structure (Seto & Shepherd, 2009). The study revealed perturbing inefficiencies as a result of spatial conditions driven by current urban planning and architectural practices. Retaining these inefficient, wasted spaces in their existing conditions only serves to contribute to the local internal vulnerability of the neighbourhood, while concurrently retrofitting these spaces present opportunities to promote climate change adaptation and mitigation strategies.

In terms of the spaces themselves, a total of 7% of the neighbourhood constitutes unused, under-utilised interstitial spaces. While these spaces are diverse in terms of size, orientation and edge definition, 88% of these spaces have very high sky view factors and 80% experience little overshadowing. Considering the material use and limited vegetation within these spaces, their contribution to the local urban heat island and potential as spaces of energy generation, food production, water collection and urban cooling nodes must be highlighted. Two significant interstitial space types that present leverage potential are accessible rooftop spaces and underutilized parking spaces. These represent 5% of the total study area and can be retrofitted with climate change adaptation and mitigation strategies.

Retrofitting these spaces has the potential to lower the local urban heat island impact, while retaining its impermeable surfaces increase the stormwater quantities for long term storage or diverting the run-off to detention ponds to recharge the groundwater table. These spaces can incorporate energy-generating PV cells to create more resilience in the local energy grids (Schneider, Duic, & Bogdan, 2007). An additional option is to use a series of roof spaces for urban agriculture initiatives, therefore developing means for local food production and employment opportunities. A series of ground-level spaces identified in Table 1 can similarly be transformed into greenspaces, cooling the immediate environment (Kleerekoper et al., 2012), and providing alternative opportunities to create public spaces.

This study developed and tested a multiple participant mixed-method process through which the urban structure of developing cities can be defined to identify and harness their hidden potential for climate change adaptation purposes. The next step is to test the method in diverse urban contexts to expose the contextual relationship between the specific district, place and available interstitial spaces. Furthermore, extending the project participants to a diverse community beyond the built environment discipline will allow for further alternative and diverse readings of the city. This can be considered as one of the stages within a co-production process to enable users to contribute their wisdom and insight in complex spatial conditions, and possibly broaden the input and nature of information that the users share during urban redevelopment initiatives. Finally, research into methods of communicating and capturing spatial data that represent specific spatial quality and leverage opportunities for diverse individuals, while using online data repositories and cell phone technology, requires further exploration.

Acknowledgements

The authors wish to thank the student group that participated that documented the Hatfield neighbourhood, Dr Christel Toskie-de Bruin for her feedback and guidance, and the anonymous referees for their helpful comments and feedback.

Disclosure statement

No potential conflict of interest was reported by the authors.

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