Urban Planning and Nature: Parametric Modelling as a Tool for the Responsive Greening of Cities

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Abstract: Using advanced parametric computational tools – and considering variables such as the size of urban areas, their population and recommended indicators of amount of green space and its proximity to residents – this paper proposes an approach to simulate optimum urban morphologies based on the application of defined large-scale green planning models such as the green belt, green wedges and hybrid approaches. Parallel patterns of growth and shrinkage have marked cities in the last decades. Furthermore, planning cities for climate-change related events and social transitions is a pressing action. Yet, while there has been an upsurge of research on the beneficial effects of green spaces and their efficient planning and implementation in cities, explorations regarding standard-based spatial simulation and modelling of future green scenarios need further research. This paper first contextualises current processes of urban and landscape transformations. Secondly, it defines the parameters used in the model and assesses the performance of selected green planning models. Finally, it shows how the proposed computational approach could become an effective quantitative tool for improving the processes of envisioning future sustainable and re-natured urban environments.

Keywords: spatial simulation; parametric modelling; green spaces; green areas; planning models

Introduction

Planning for climate-change related events and social transitions is a pressing action. With predictions of an increase of urban population to 70% by 2050, with potential resultant natural capital loss, discourses on re-naturing cities, nature-based solutions and green infrastructure have recently come to the fore as paradigms for the re-conceptualisation of sustainable and resilient urban scenarios. The benefits of nature for humans have been systematically studied across several disciplines and promoted in public policies worldwide, including the provision of adequate amount of accessible green space in cities. For instance, the United Nations Sustainable Development Goal 11 states that by 2030 cities should provide universal access to safe, inclusive and accessible green and public spaces.

While the multiple benefits of ecosystem services in urban areas have been boasted, urbanity remains an important value in urban design and planning discourses. The question of balance is important, but often not precisely posed in urban studies. Current understanding of cities as significant *loci* for the integration of ecological and socio-cultural systems points to the importance of urban form in supporting or hindering such relationship.

Given the need for cities to both accommodate anthropic needs and non-human life, while reducing our impact on the planet; an integrative and systemic approach to planning and delivering new, greener urban environments is required. As such, explorations regarding standard-based spatial simulation and modelling of future green scenarios need further research. The central aim of this article is to investigate how the use of planning models could allow cities to be greener by the virtue of their form. Through a parametric computation modelling approach and considering key indicators for the amount and distribution of green spaces in urban areas, it explores the potentialities and shortcomings of models such as the green belt, the green wedges and hybrid approaches. In so doing, it analyses how the application of such green planning models perform in terms of proximity of residents to green spaces. Subsequently, the article discusses how hybridism can lead to optimum urban morphologies. The proposed approach allows green infrastructure solutions to maximise the benefits of each individual strategy, helping generate hybrid, site-specific and responsive visions for environmentally just greener cities.

Cities and green space planning models

Perspectives from urban planning and design on the roles of urban form in providing a framework for a harmonious relationship between built-up and green areas have regained attention. Lynch (1981) detailed city models such as the Core, Start City and Linear City; which were subsequently investigated by Frey (1998) in relation to sustainability indicators. Building on these studies, this paper explores such typologies at city scale, focusing on how associated green planning models based on the green belt, green wedges and hybrid approaches including greenways perform in terms of provision and distribution of green spaces.

Green belts have, since Howard's Garden City idea, marked planning debates. Originally conceived to control urban sprawl, create a buffer zone between urban areas and safeguard agricultural land; already in the early twentieth century green belts received severe condemnation for strangling the cities' ability to expand and for keeping most of the open spaces at the fringe, away from the densely populated central urban areas, where most of people lived (Eberstadt, 1911). Eberstadt's criticism with regards to the unbalanced distribution of green spaces in green-belt cases was aimed at the very core of its inherent structure: that it can allow for the outer ring of urbanization direct access to green space, but not for the inner areas. In the current context of global population growth, this model has been deemed inflexible to cope with the need to accommodate more urban dwellers, to enhance the presence of nature in cities and to bring ecosystem services close to inner-city dwellers (Amati and Taylor, 2010; Lemes de Oliveira, 2019).

The green wedges model is defined as a particular articulation between open and built-up spaces in which wedges of greenery opening out towards the edge of the urban area are interspersed between development areas. It was conceived as a way to ensure that urban growth could happen without compromising the amount of green spaces available in cities and their accessibility to inhabitants. (Lemes de Oliveira, 2017). If provision of large-scale green spaces close to dwellers is this model's main intrinsic positive characteristic regarding its form, its main shortcoming is the potential disaggregation of built-up areas as the wedge widens beyond walkable distances. Size matters also as it has an effect on the range of human activities and ecosystem services possible (Forman and Godron, 1986). Stockholm's Regional Plan, for instance, defined that green wedges should be at least 500m. However, examples vary and in cases, in their thinner ends, green wedges can become more alike tree-lined streets and greenways, and in the other end of the spectrum, urban forests.

Greenways, as corridors of landscape through an urban area, offer flexibility in implementation. Normally narrow in width and long in extension, such areas have the potential to reach various portions of the urban fabric, providing excellent accessibility (Ahern, 1995; Hellmund and Smith, 2006). Examples such as Cheonggyecheon in Seoul, Madrid Río Park in Madrid and Emerald Necklace in Boston are associated with watercourses and present varying widths from nearly 40m to more than 250m. Greenways' often-narrow width can be limiting to the provision of activities and ecological functions (Smith and Hellmund, 1993).

The question of quantity, accessibility and distance

The question of how much green space cities should have as well as their adequate distribution have been objects of much consideration. The provision of ecosystem services is dependent on adequate amounts of natural environment provided and the larger the space the more ecological habitats and human activities can be accommodated. The benefit being directed both at human and other species. Various studies found that the total amount of green space within the living environment seemed to be the key variable to direct influence people's health (Keniger *et al.*, 2013; van den Berg *et al.*, 2015). For instance, De Vries *et al.* (2003) reported that the total amount of green space within the living environment is a crucial factor, and that an increase of only 10% of green space could result in the decrease in the number of symptoms equivalent to a reduction of 5 years in age. In addition, such effects could be seen within a 3km radius.

The identification of clear standards is problematic, as many terms with varying definitions and interpretations are used, such as open spaces, open areas, green spaces, public spaces etc. However, area-based and population-based indicators have been considered. With regards to the former, already in the 19th century classic planning treatises such as the tome by Baumeister suggested a ratio of 50% of open spaces and that of Stübben 30% of green spaces (Baumeister, 1876; Stübben, 1890). The ratio of 30% appears in several approaches in planning history and bears relevance with contemporary targets, as can be seen in the cases of New York (The City of New York, 2011) and Copenhagen, which have each a quarter of their area destined to accessible green space; and London, with over 30%. The surge of eco-cities in china in the early 2000s saw ambitious targets. For example, Songdo in South Korea was planned to have 34% of land dedicated to green and blue spaces and Dongtan in China, to be close to 40% (Lemes de Oliveira, 2013).

In regards to a population-based approach, it is noteworthy mentioning the one defined in the UK by the National Playing Fields Association. Originated in the 1930s, it defined the Six Acre Standard (24,000 square meters/1,000 people). This has served as a benchmark in various plans since the post-war period. At the beginning of the War, the average open space provision for some of the largest cities in England was less than 3 acres (12,140 square metres) per 1,000 people (Lemes de Oliveira, 2017). Abercrombie and Foreshaw's County of London Plan 1943 aimed for seven acres per 1,000 people, four within the boundaries of the council and three beyond. For the Greater London Plan 1944, Abercrombie increased the ratio to 10 acres per 1,000 people. Highly influential, this plan became a fundamental reference for planning cities and regions in the postwar period. The Six Acre Standard is still applied today.

Proximity to a green space within a 10-minute walk (800m) frequently appears as a key indicator (Fields in Trust, 2018; Frey, 1998). Yet, several authors relate walking time, distance and size of green spaces (Stessens *et al.*, 2017). For instance, the Accessible Natural Greenspace Standard (ANGSt) recommends that all should have access to green space of at least two hectares in size, no more than 300 metres (2-3 minutes) from home; a 20 hectare site within two kilometres (25-minute walk); one 100 hectare site within five kilometres; and one accessible 500 hectare site within ten kilometres of home. When focusing on walking distances, studies tend to limit the distance considered up to 3km. Maas *et al*. (2006), for instance, showed that in areas where 90% of the environment around the home was green, only 10.2% of the residents felt unhealthy, compared to 15.5% in areas where only 10% of the environment was green. This was also perceived in the range up to 3km. Figure 1 shows the parametres employed in this study.

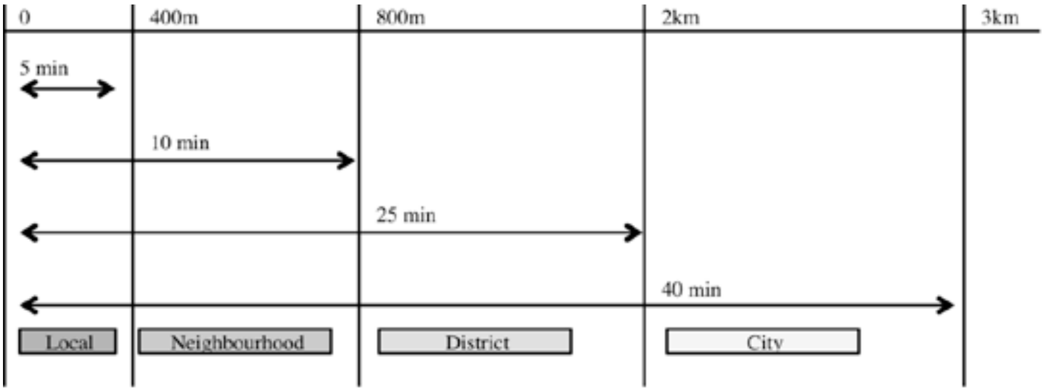

Figure 1. Correlated *time-distance-scale* parametres to urban green spaces

Distance decay in the use of green spaces is commonly found, with high association between distance and use (Nielsen and Hansen, 2007). Grahn and Stigsdotter reported that green spaces within 300m of home rendered on average 2.7 visits a week, but if the distance was of one kilometre the frequency of visits dropped to once a week. Notwithstanding this, larger green spaces even if further away often allow for a wider range of activities for various groups (Lemes de Oliveira, 2017). Taking distance, walking time and size of green spaces in consideration, Stessen *et al.* (2017) brought together these key indicators in relation to the different urban scales, from local to metropolitan. This article builds on this approach to inform the computation model and test the planning models described previously. It focuses on the area-based approach as described below.

Modelling balance between urbanization and green spaces

Methodology

The computational model was created using Grasshopper, an algorithm-based plug-in for Rhinoceros. It allows for the concomitant managing and manipulation of several parameters and simultaneous visualisation of outcomes. The model combined information about a city's size, amount of green space required and accessibility on foot according to their distribution in the key green space planning models under study. The computational model allows for the analysis of cities of virtually any size. However, this paper concentrates on medium-sized cities, applying the models on 40 km^2 and 70 km^2 using 30% green space as a constant (figure 2-4).

The model was employed to explore the intrinsic potentialities and shortcomings of such green space planning frameworks. The accessibility to green spaces in each green planning model was measured and compared. The idea of a nested hierarchy as described in Stessen *et al.* (2017) was used in seeking common ground in relating multiple scales both of urban areas and green spaces, and the time dimension. The analysis is kept to local, neighbourhood, district and city scales. As such, the percentage of areas accessible within 5 minutes, 10 minutes, 25 minutes, and more than a 25-minute walk have been measured and visualised for each of the green planning models.

Specific indicators for the green space planning models were limited to achieving a width of 500m at the centre of green wedges; a minimum width of 40m for the thinner ends of green wedges and for greenways; and in the case of the green belt that it was concentrated outside the urban fabric, and distributed as one or two green belts.

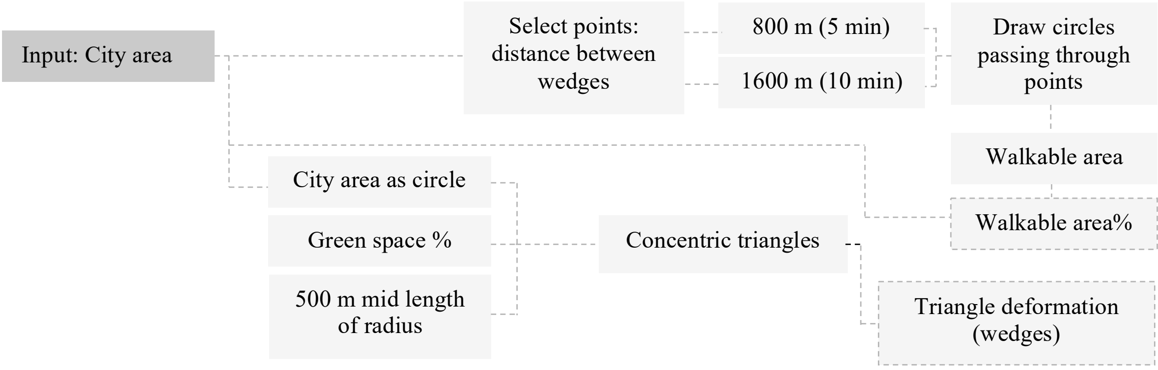

Figure 2. Diagram explaining the modelling methodology using grasshopper for the green wedges example

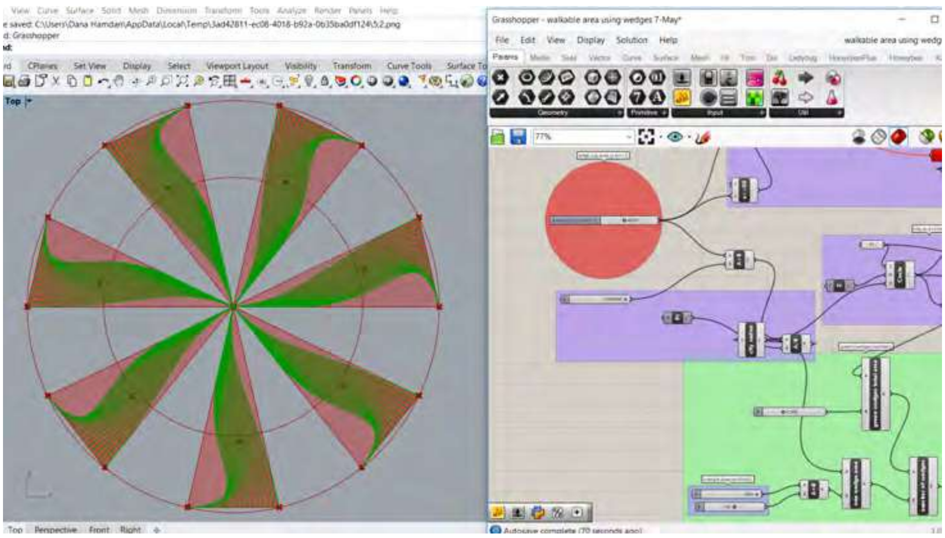

Figure 3. Generation of the green wedges using the grasshopper script

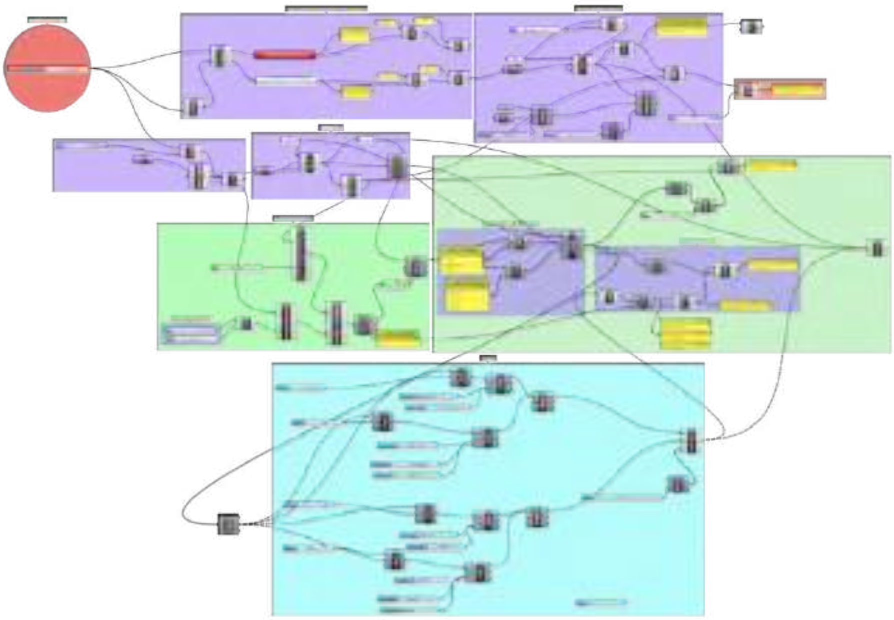

Figure 4. Full script of the generation of green wedges

The green space planning models

[Green belts]

Two green belt cases were applied to two city sizes, for a total of four test models. The first case presented the entire green belt, which is assumed as 30% green space of the city's total area, as a single belt on the perimeter of the city. This was applied for the 40 km^2 and 70 km^2 cities. The second case involved splitting the assumed 30% green space into two green belts: the first one at the perimeter of the city and the second at half of the city radius, functioning as a greenway. Similarly, this was applied to the 40 km^2 and 70 km^2 cities.

In the first case, belt widths amounted to 583m and 772m for the 40 km^2 and 70 km^2 cities respectively. The percentage of the area accessible within a 5-minute walk are 27.7% and 23.7%, reaching 52.9% and 44.2% when considering a 10-minute walk. Just over 86% in the smaller city and 75% in the larger have access to a green space within a 25-minute walk (figure 5). In the second case, belt widths are narrower, amounting to 385m and 500m for the 40 km^2 and 70 km^2 cities respectively. The accessibility ratios rose to 60.1% and 42.2% within a 5-minute walk and to just above 97% and 82% within 10 minutes (figure 6). Clearly, the two-belt model provides significantly higher walkable area, especially in creating zones within 5 and 10 minute walking distances. In the smaller city nearly 100% of the built-up area is within a 10-minute walk of a green space. In cities of both sizes, this model ensures that 100% of the urban area can access a green space on foot within 25 minutes. On the other hand, it is worth stressing that the analysis focused on accessibility to green spaces, hence does not consider the ecosystem services that can have better performance for instance at larger continuous green spaces, which could suggest a better performance for the single belt model.

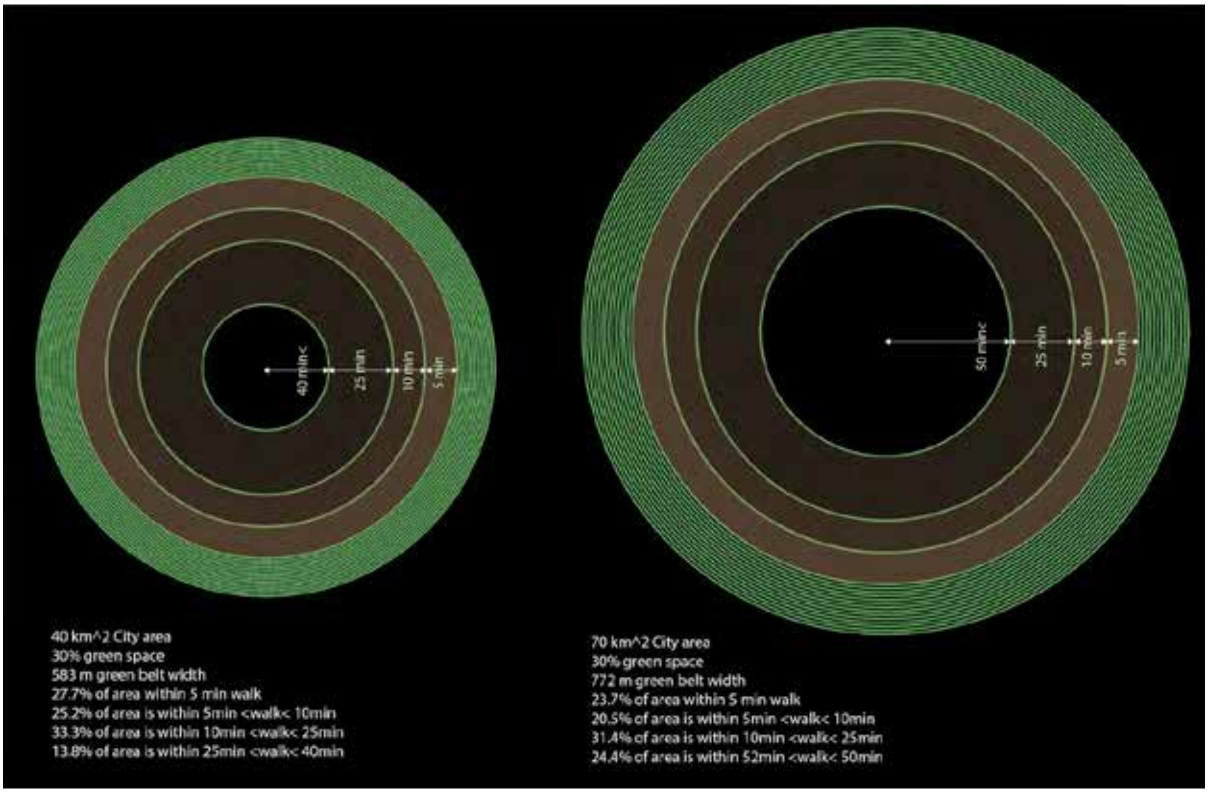

Figure 5. Walkability assessment of a single green belt at the perimeter of a 40 km^2 city (left) and a 70 km^2 city (right)

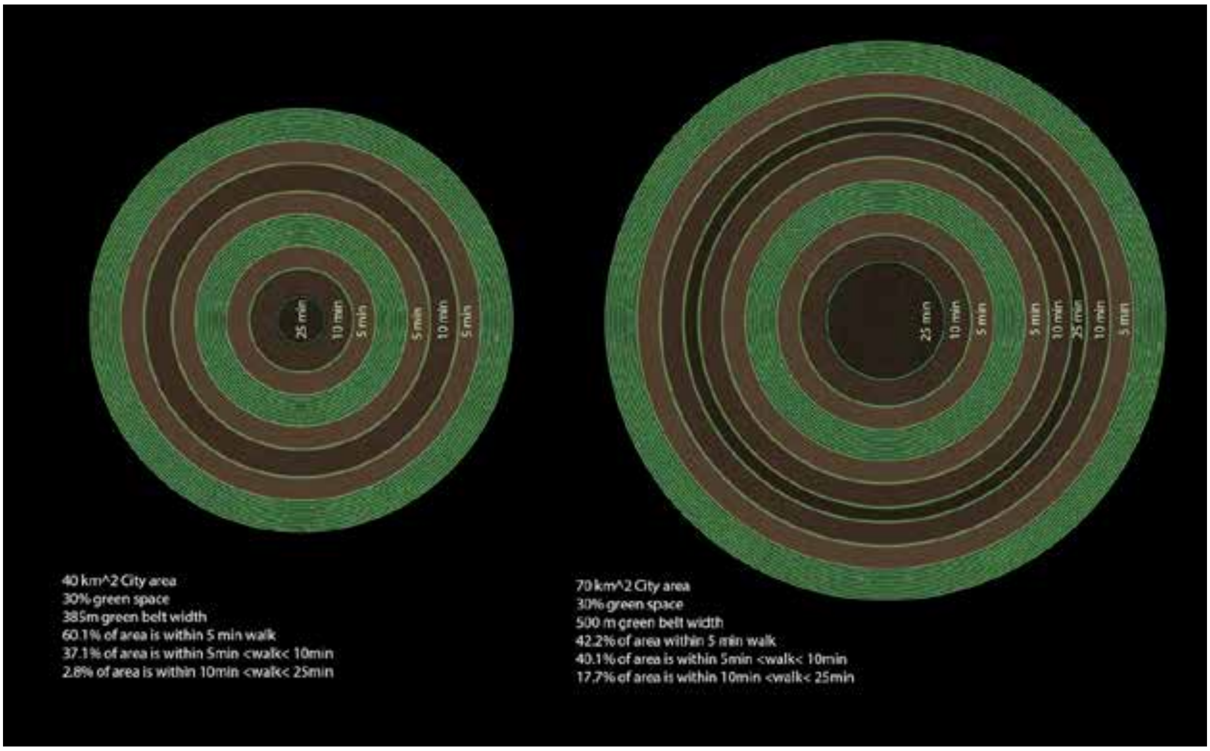

Figure 6. Walkability assessment of two green belts at the perimeter and mid-radius of the city. Applied to a 40 km^2 (left) and 70 km^2 cities (right).

[Green wedges]

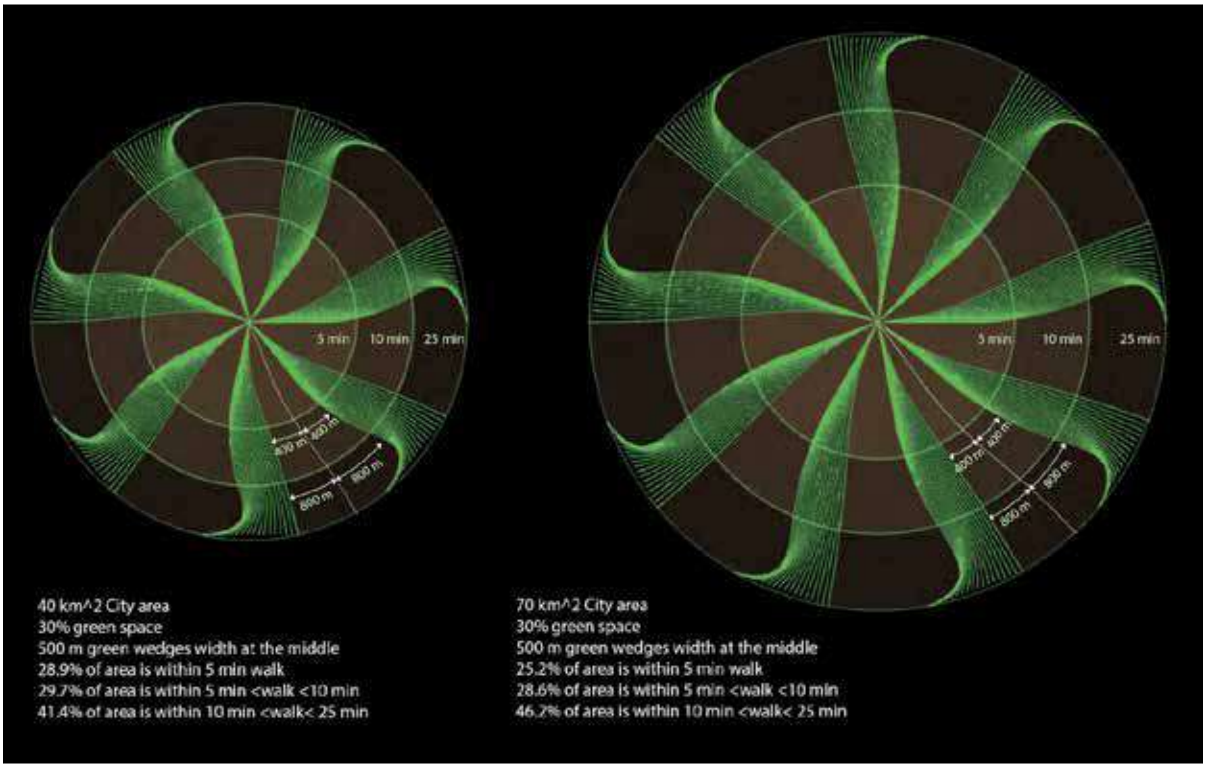

Figure 7. Walkability assessment of green wedges model applied to a 40 km^2 (left) and a 70 km^2 city (right).

The green wedge model was also explored. The created algorithm calculated how many green wedges were needed using as inputs the city size, considering 30% of the city area as green space, which was split into equal parts equally distributed, and 500m as the minimum width of the wedges at the middle. Such 500m cross-section at half the radius of the city was employed in order to facilitate the provision of a range of ecosystem services in the green wedges (Lemes de Oliveira, 2017). The location at which the distance between the green wedges is 800m (5-minute walking time to a green wedge from the centre line) was defined in the algorithm using basic trigonometry. Similarly, the distance of 1600m between the wedges (10-minute walk) and less than 4000m (less than 25-minute walk) were graphically represented (See figure 7).

The model generated 7 green wedges for the 40 km^2 and 9 for the 70 km^2 cities respectively. The percentage of the total area accessible within a 5-minute walk are 28.9% and 25.2%, reaching 58.6% and 53.8% when considering a 10-minute walk. Both cities would allow for all to access a green space on foot within a 25-minute walk.

The green wedge model is better performing than the single green belt model in terms of accessibility for both city sizes across the different scales. However, the two-belts model also provides 100% coverage within the 25-min range and significantly outperforms the green wedge model in the local and neighbourhood scales, as when placed at the end of the 10-minute zone it provides a counterpoint to the wedge's tendency for distances to increase as they widen towards the edge of the city.

When discussing performance measures of green spaces, green wedges (as represented in the models) could create a more fragmented urban form in comparison with the single green belt model, as well as less continuous green space. However, the longitudinal distribution of green space across the radius of the city can provide better distribution of green areas across the city's different zones, which can contribute to a more equitable provision, as well as facilitate certain ecosystem services such as air flow and exchange and reduction in the heat island effect.

[Combined model: green belt and green wedges]

In order to analyse the combined effect of green belts and wedges on accessibility to green areas on foot, two scenarios were considered for both the 40 km^2 and 70 km^2 city areas, for a total of 4 tests models. All the test models have 30% green space of the city area. The first scenario uses 4 green wedges, while the second considered the same number of green wedges as in the models presented previously (7 and 9 wedges for the 40 km^2 and 70 km^2 respectively). The width of the wedges was kept as 500m at the middle of the radius for the 7 and 9 wedges. The width of each green belt is 120m and 170m for the two city sizes, which was calculated parametrically using the algorithm to ensure that, combined with the wedges, the total amount of green space reached 30% of the total area. It is worth pointing out that the model allows for a range of combinations of sizes for belts and wedges, for instance where the wedges can be thinner and the belts thicker. However, in this paper we limited the analysis by treating the wedges' thickness as a constant, consequently allowing the belts' thickness to vary.

In the 40 km^2 city, both models with 4 and 7 wedges achieve 100% of green space accessibility within a 10-minute walk, with the latter performing better in the 5-minute range (64.2% compared to 54.4%). In turn, in the larger city, the 4 and 9 wedges combined models achieve 100% accessibility within the 25-minute range and the same ratio (77.8%) at the 10-minute range, with the one with more wedges performing better (59.5% compared to 39.3%) within the 5-minute walking distance (see figure 8). When analysed against the non-hybrid models, the combined wedge-belt models of 7 wedges for a city of 40 km^2 and and 9 wedges for a city of 70 km^2 outperform all the other models.

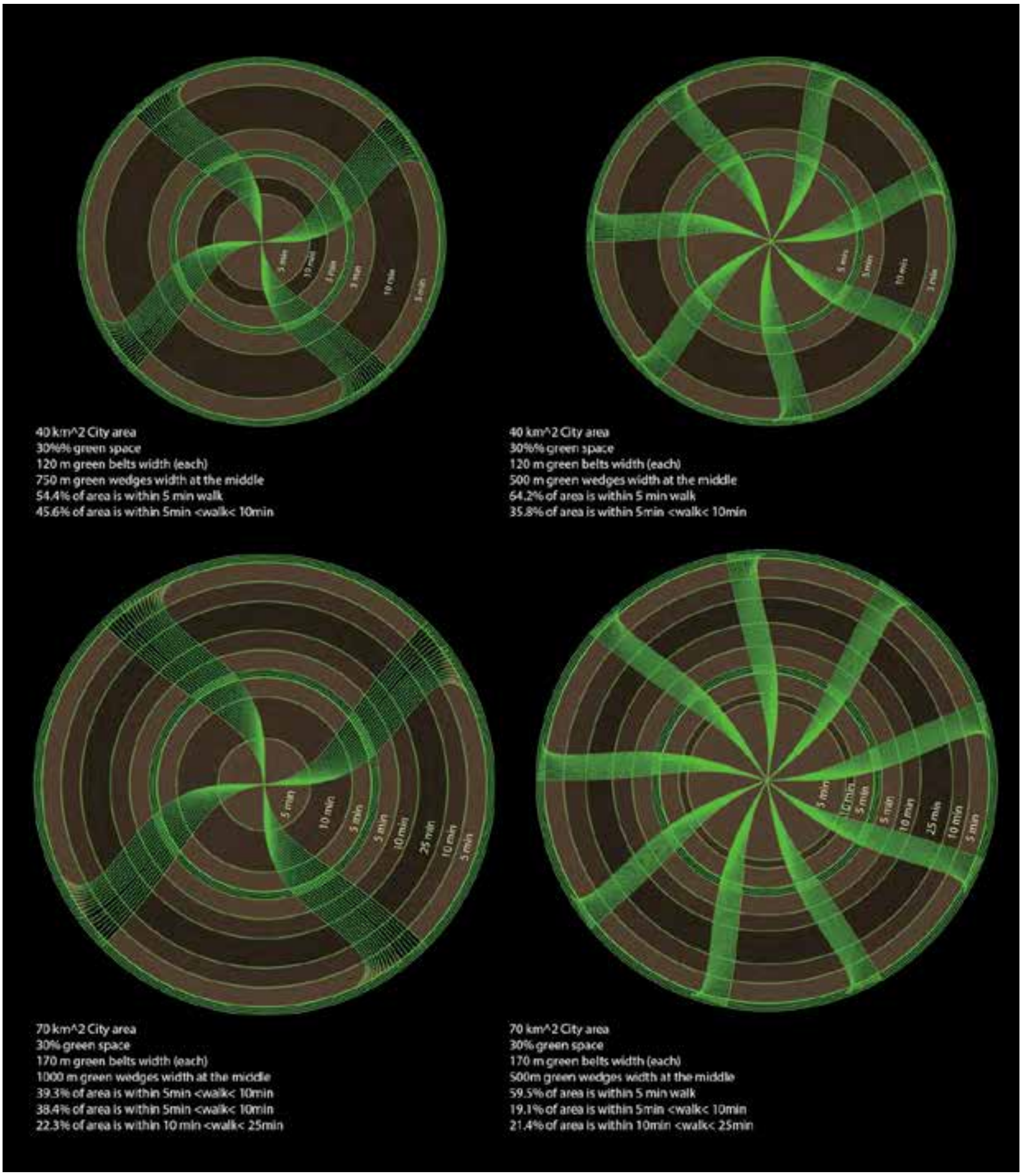

Figure 8. Walkability assessment of combined models of green wedges and green belts applied to a 40 km^2 (top two) and a 70 km^2 (bottom two) city using the following possible distribution of the wedges: 4 wedges (left) and 7 and 9 wedges (right), and two green belts in each scheme.

Table 1. Summarises the walkability performance of each of the green space planning models

Green model	5 min walk	5 min<walk<10 min	10 min<walk<25 min	More than 25 min walk
Single green belt	27.7%	25.2%	33.3%	13.8%
	23.7%	20.5%	31.4%	24.4%
Two green belts	60.1%	37.1%	2.8%	N/A
	42.2%	40.1%	17.7%	N/A
Green wedges	28.9%	29.7%	41.4%	N/A
	25.2%	28.6%	46.2%	N/A
Combined wedge-belt (4 wedges)	54.4%	45.6%	N/A	N/A
	39.3%	38.4%	22.3%	N/A
Combined wedge-belt (7 and 9 wedges)	64.2%	35.8%	N/A	N/A
	59.5%	19.1%	21.4%	N/A

40 km^2 city   70 km^2 city

Conclusions

This paper shows that city models can be valuable imprints for the re-balancing of our cities and nature, and in particular to the provision of ecosystem services close to where people live, work and recreate. The definition of parametric modelling tools that allow for concomitant consideration of a range of attributes related to the size and distribution of both green and non-green areas can support cities in defining re-naturing strategies, in particular in times of change. Urban form matters with regards to the provision of adequate amounts of and accessibility to green spaces in cities.

The standard green belt model can concentrate the largest amount of green space and provide good accessibility to green spaces in the outer fringes, at the expense of accessibility from the central area, which falls out of the 25-minute walking range. The green wedge model in turn allows for good accessibility across the city. The research has shown that its application alone can ensure that nearly a third of the built-up area can be within a 5-minute walk of a green area and close to 60% of the city can be within the 10-minute range. Additionally, this model ensures that 100% of the city is within the 25-minute walking range and that an equal distribution of green spaces across the city can be achieved. They can also provide a direct green link between the city centre and the non-urban areas. The two-belt model presents the highest performance of the non-hybrid models, with the large majority of the city within the 10-minute range (See table 1).

The combined wedge-belt models with 7-9 wedges are the highest performing in terms of walkability. They can also provide enhanced environmental benefits. The wedges are connected by the belts, and the green space reaches all the zones of the city including the city center. This is unlike the two-belts model where the two main green spaces do not reach the central zone of the city, which usually is where the urban heat island effect can be more manifested.

Given the fact that cities are undergoing constant transformation potentialised by competing pressures and challenges, seeking socio-cultural and ecological-environmental equilibrium is crucial for the ongoing sustainability and resiliece of urban habitats. Parametric tools can allow for the manipulation of complexity in inputs and continuous assessment of outputs. The range of planning models can flexibly consider aspects of urban cohesion and the maximisation of specific ecosystem services in the decision making process, contributing to the creation of cities in balance with nature.

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