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Natural Capital Impact Assessment
for New Urban Developments

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ABSTRACT: *Under pressures of climate change and population growth, it is crucial to address water security and sustainable urban development in our cities. This challenge is particularly important for London, where a shortage of housing has been experienced during last decades and the region is considered highly vulnerable to water shortages and floods. According to the Greater London Authority (GLA), an average of 66,000 new homes per year should be built until 2041. However, assessing impacts of such urban growth on environmental management and protection is complex and difficult to evaluate.*
This creates a need to determine the extent to which Ecosystem Services (ES), or the benefits provided by the functioning natural environment in the form of Urban Natural Capita (UNC), are essential to the wellbeing of current and future urban dwellers and how costly it may be to provide them. This research aims to create an impact assessment framework for Urban Natural Capital (UNC) for new urban developments, which will provide crucial indicators to assess sustainability at an urban development scale. The results will be used to inform improved urban design in the context of water and environmental management, including Blue Green Infrastructure (BGI) solutions, and showcase the benefits that lead to better decisions and sustainable urban development.
KEYWORDS: *Urban Natural Capital, Sustainability, Urban Developments, Ecosystem Services*

1. INTRODUCTION

Under the increasing pressures of climate change and population growth at the global level, it is crucial to address water security and sustainable urban development. Urban Infrastructure Systems (UIS) involve multiple sectors, including water, land, transport and housing. These infrastructures interact with each other and put constant pressures on their surrounding environment and human wellbeing in the form of flood risk, water shortages, air and water pollution, and Urban Heat Island (UHI) effect [1].

Nowadays, more than 50% of the world's population live in urban areas, and this is predicted to reach 66% by 2050 [2]. This level of growth will be particularly critical in London, where population is projected to increase by 70,000 people every year, reaching 10.8 million citizens in 2041 [3].

The capital is one of the most at-risk UK's urban areas to future climate change, being particularly vulnerable to water scarcity, heat waves, flooding and air quality problems [3, 4, 5]. According to the Greater London Authority (GLA) and their new London Plan, an average of 66,000 new homes per year should be built in the city until 2041 [3].

However, the relationship between urbanisation and environmental management is very complex and has not been sufficiently addressed yet. Urbanisation is a difficult spatiotemporal process that influences areas beyond the urban cores, being a difficult process to control, quantify and plan [6]. Increased urbanisation can be detrimental to natural environment's connectivity and condition, which are key components of resilience to climate change [7, 1].

Ecosystem Services (ES) and Natural Capital (NC) assessment is growing in popularity as an innovative and powerful method to evaluate the level of sustainability for new urban developments. The results from this type of assessment are generally presented as a series of numerical scores (positive or negative), but little evidence is available about their combination with spatial representation of the urban development. Hence, a valuable method that combines Urban Natural Capital (UNC) values with graphical Geographical Information Systems (GIS) maps is performed in this study, making the process for sustainable urban design more effective and reliable, which may ultimately lead to better planning decisions.

1.2 Sustainable urban infrastructure solutions

Nature Based Solutions (NBS) are broadly defined as solutions inspired and supported by nature that simultaneously provide environmental, social and economic benefits to citizens [8]. They also have a series of co-benefits, such as improving health and quality of life, and the attractiveness of the place [8]. The NBS concept includes Blue Green Infrastructure (BGI) and other sustainable concepts such as Sustainable Drainage Systems (SuDS), Ecological Engineering and Water Sensitive Urban Design (WSUD). Some examples of BGI include: street trees; parks and open spaces; permeable paving; engineered stormwater controls (bioswales, rain gardens or retention ponds); green roofs; green facades; waterways and wetlands; or, urban gardens [9].

In parallel to this, Ecosystem Services (ES) are understood as all the benefits that citizens and human beings obtain from natural ecosystems [10]. In economic terms, natural ecosystems are also understood as a Natural Capital (NC), accounting for all the assets that the natural environment provides in the context of ES. These include soil, air, water and all living organisms [11].

BGI benefits can outweigh those of traditional hard infrastructure based on reinforced concrete, also known as grey infrastructure [12]. In order to achieve a good level of urban sustainability and a large number of ES, it would be necessary to evaluate the optimal combination of BG vs grey interventions to be implemented in our cities.

1.3 Complexity of urban interactions

Despite the fact that numerous investigations recently tried to integrate urban planning design with water and housing systems, many challenges still remain. These challenges are very clear if we analyse London's urban environment, which is currently in danger of critical deterioration due to climate change and a wide variety of constant pressures [3].

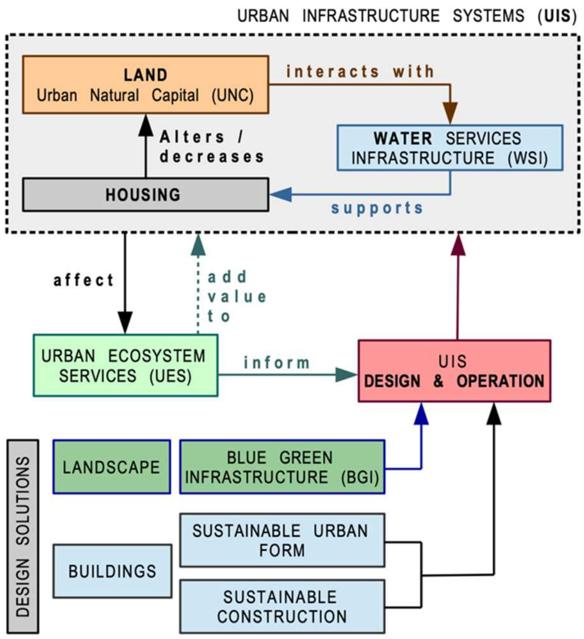

Figure 1: Systems thinking diagram that interlinks Urban Infrastructure Systems (UIS) with Urban Ecosystem Services (UES) and the relationship of sustainable design solutions to the design and operation of UIS.

More housing growth requires more water to be abstracted, which is finally converted into wastewater once it is treated, stored and consumed. This wastewater discharges from sewage treatment plants are released back to the natural environment and affect the final amount of ES provided to citizens. In order to maintain a sustainable process and to manage urban water efficiently, it will be necessary to re-think the urban design concept from a systems perspective (see Fig. 1).

Although Urban Infrastructure Systems (UIS) might include transport or energy production, in this study they are comprised of the three main elements seen in Figure 1: 1) Housing, 2) Land, and 3) Water Services Infrastructure (WSI). These three urban elements are always interconnected and depend on, and affect each other. Land includes all the Blue and Green assets that are internal part of the system, that is the Urban Natural Capital (UNC); while housing includes all the building infrastructure and any impervious surface necessary to support it, such as parking, roads or paths. As conceptualised in Figure 1, UIS directly affect the Urban Ecosystem Services (UES), which at the same time also add value to the urban infrastructure (UIS). Therefore, the sustainable design solutions proposed for landscape and building areas will directly affect the performance and operation of the UIS.

1.4 CAMELLIA research project

This research is a key element of the Community Water Management for a Liveable London (CAMELLIA) research programme, which is focused on sustainable urban water management in London. CAMELLIA has four London-based case studies (Mogden, Enfield, Southwark and Thamesmead), each reflecting different key issues of urban water management (see Fig. 2). Among them, Thamesmead will be this work's main case study, where a major redevelopment plan is expected to emerge during the next 20 years [3].

CAMELLIA is supported by communities, policymakers and industry; it aims to transform collaborative water management to support the provision of lower cost and better performing water infrastructure in the context of significant housing development, whilst improving people's local environments and their quality of life.

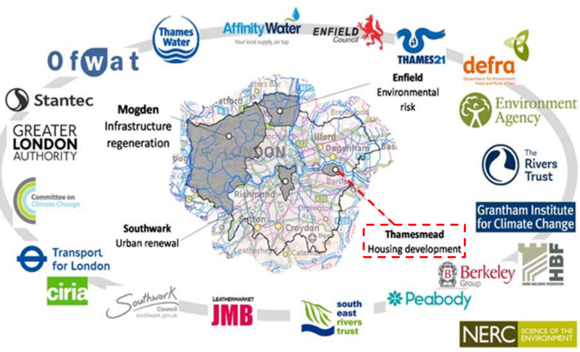

Figure 2: Case study areas inside CAMELLIA research project (London map with Thamesmead highlighted in red) and partners involved (logos around the map). (Source: CAMELLIA)

2. METHODOLOGY

2.1 Thamesmead as main case study area

Thamesmead is a 750-ha neighbourhood located in Shout-East London where around 150 ha are considered blue or green space. Following a report conducted by Vivid Economics, the total NC potential value provided by Thamesmead's blue and green-space is estimated to be at least £306 million or £257 per person per year [3]. Despite this abundant natural value, this blue and greenspace is not appropriately used by their citizens and large areas are even inaccessible.

As mentioned in Section 1.4, this district is undergoing a large urban regeneration programme and its major development will be Thamesmead Waterfront Development Plan (TMWDP). This scheme will include more than 11,500 new homes and a contemporary renovated masterplan carried out by the Peabody Housing Association. TMWDP, which comprises a total area of 100 ha and embraces almost 3 km of underdeveloped river waterfront, will be our main case study area to test our different urban design proposals.

2.2 Natural Capital impact assessment

Engineers and scientists need to determine the extent to which certain ES are essential to the welfare of current and future generations and how costly it may be to protect and conserve them. Accounting for the Urban Natural is a crucial indicator of our cities' level of sustainability and finding the most reliable type of assessment is a challenging task that needs to be analysed.

As already explained in previous sections, NC accounting will be this study's starting point in order to understand the environmental impact created by new housing developments. At this stage, the studies are focused only on the design aspect, leaving the operation of the system mentioned in Section 1.3 for future stages of the work (see Fig. 1).

There are different tools that evaluate Natural Capital (NC), two of the most commonly used being NCPT (Natural Capital Planning Tool; Hölzinger et al., 2019) and InVEST (Integrated Valuation of Ecosystem Services and Trade-offs; Sharp et al., 2018). Between them, NCPT is chosen because it is more appropriately designed for urban developments and fits within the general design process explained in Figure 1.

Despite its appropriate functionality, the NCPT only provides numerical scores for Ecosystem Services (ES) and lacks a graphical representation of land uses. Therefore, an important innovation presented in this work is the ability to link the pre- and post-development land-use areas of the site with a GIS software. For this, QGIS (Cavallini et al., 2019) is used because it is a free-open source platform and can be easily shared with a range of professionals.

2.3 Urban design scenarios

Three different urban design scenarios of land uses are suggested in order to compare different levels of environmental impact. But, before presenting these three urban design scenarios, it is necessary to understand the pre-development land-use map, which will act as the initial baseline for all of them. This is represented based on research data previously collected and supplemented by OpenStreetMap and Google satellite maps.

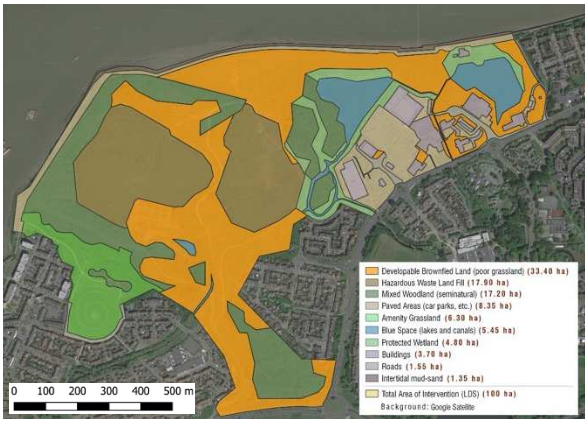

Figure 4: Pre-development land-use map for Thamesmead Waterfront Development Plan.

As seen in Fig. 4, most of the land at the pre-development state is currently developable brownfield land and hazardous waste land fill. The latter cannot be used for building, but it might be transformed into a natural reserve. On the other hand, the blue space (lakes and canals), the amenity grassland and the protected wetland must be preserved [7]. Apart from an existing and functioning water-pump station, all the existing buildings will be removed and redesigned in all three design options.

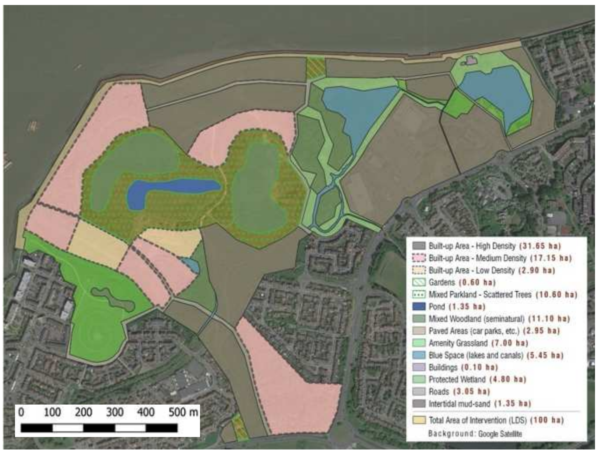

Figure 5: Post-development Land-Use map for Thamesmead Waterfront Development Plan. Scenario 1 – "Adverse".

Based on initial constraints previously explained such as the hazardous waste land fill areas or the protected wetlands, and in order to find a realistic but "adverse scenario", the first urban layout is proposed (see Fig. 5). Scenario 1 represents a traditional way of building [14] and does not consider any sustainable urban form, such as appropriate orientation or green roofs. In this case, some land uses are transformed, such as developable brownfield or hazardous waste land; new ones emerge, such as built-up areas (high, medium and low density), gardens, mixed parkland or pond. These built-up areas with different types of densities are built with traditional ways of construction, being considered non-sustainable buildings.

As aforementioned, in Scenario 1 the blue space, protected wetland and intertidal mud-sand are preserved and have not been changed. Other land-uses, such as mixed woodland and amenity grassland, have been decreased in some parts but augmented elsewhere, especially where there is currently hazardous waste land fill.

The next scenario, called "intermediate", has the same number of built-up hectares as Scenario 1, but instead of being high-, medium-, or low-density built-up areas, those are replaced by "buildings covered with green roofs" or "buildings with green walls" land uses. These two land uses are the only sustainable building options given by the NCPT. This is therefore seen as an important limitation of the tool, as BGI option cannot be implemented in the design properly. In the same way, the previous "roads" have been replaced by "local green roads"; while "paved areas (car parks, etc.)" are transformed into "gardens" (including the Thames path). NCPT does not give options for BGI land uses, such as "permeable paving" or "swales", which constitutes another important limitation of the tool.

Figure 6: Post-development Land-Use map for Thamesmead Waterfront Development Plan. Scenario 3 – "Favourable".

The third option, called "favourable", is based on a completely new urban layout design (see Figure 6). In this case, instead of keeping the same areas and changing only the "building typologies" (which would not be possible due to the already explained NCPT constraints); more green, blue and recreation spaces are arranged around the built-up areas to increase the ES received. This scenario is based on compact densities and BGI around them, which is proven to be a more sustainable option for future cities than low-density layouts [14].

Additionally, a series of further planning decisions is taken in Scenario 3: a) most existing woodland is preserved; b) more woodland and pond areas are added inside the parkland; c) gardens (which represent BGI) are placed around most of the building blocks; and, d) blue space is considerably increased with new lakes and a new canal network.

2.4 Densities for built-up areas

In terms of number of houses, the building developer, Peabody Housing Association, has a clear target of 11,500 new homes for this large urban development of TMWDP. It is demonstrated inside the literature that the concept of density is quite critical and is based on specific thresholds. Therefore, the values for high-, medium- or low-density can be defined differently depending on the author and always will depend on the particular context of the development and its surroundings [14].

ESTIMATED DENSITIES FOR EVERY URBAN DESIGN SCENARIO

	Scenario 1 - Adverse		
	N. of ha	Dwellings per ha	N. of dwellings
High-Density	31.65	280	8,862
Medium-Density	17.15	140	2,401
Low-Density	2.90	50	145
TOTAL N. DWELLINGS	**11,408 / 11,500**		
	Scenario 2 - Intermediate		
	N. of ha	Dwellings per ha	N. of dwellings
Buildings w. green roofs	31.65	280	8,862
Buildings w. green walls	20.05	130	2,607
TOTAL N. DWELLINGS	**11,469 / 11,500**		
	Scenario 3 - Favourable		
	N. of ha	Dwellings per ha	N. of dwellings
Buildings w. green roofs (HD)	10	800	8,000
Buildings w. green roofs (MD)	8.75	400	3,500
TOTAL N. DWELLINGS	**11,500 / 11,500**		

Table 1. Estimated densities for the built-up areas for every urban design scenario studied and compared to Peabody's target of 11,500 new homes.

Hence, the number of dwellings per hectare inside these built-up areas has been estimated in order to achieve Peabody's target for each urban design scenario previously presented (Table 1). These estimated densities provide a general idea of the housing typologies that might be included in every urban design scenario.

3. RESULTS

The NCPT analyses ten Urban Ecosystem Services (UES), providing NC impact scores for each of them. These ten UES evaluated by the NCPT are: 1) harvested products, 2) biodiversity, 3) aesthetic values, 4) recreation, 5) water quality regulation, 6) flood risk regulation, 7) air quality regulation, 8) local climate regulation, 9) global climate regulation and, 10) soil contamination.

Additionally, NCPT also gives the number of ES achieving Environmental Net Gain (ENG), which represents the environmental impacts of habitat change. It is important to highlight that, although these scores might be highly valuable indicators, they should always be deployed alongside with some expert knowledge in the field.

As explained in Section 2.3, the pre-development land-use map will be the initial baseline for all three scenarios. Once all the land-use data are processed using QGIS and the number of hectares for every land use are quantified in every scenario, these are introduced into the NCPT. This is combined with other types of data such as heat exposure, proportion of built-up area, flood risk zone, drinking water safeguard zone, air quality management area, accessibility, size of greenspace site, and soil drainage. At the end, the tool provides NC Impact Scores for every UES analysed and NC Net-gains for each designed urban scenario. At this point, it is remarkable to see how small changes in urban layout and land uses are able to provide significant variations in the NC impact assessment (see results in Table 2).

Natural Capital Impact of Thamesmead Waterfront Development						
	Scenario 1 "Adverse"		Scenario 2 "Intermediate"		Scenario 3 "Favourable"	
Ecosystem Services (ES)	NC Impact Score	NC Net-Gains	NC Impact Score	NC Net-Gains	NC Impact Score	NC Net-Gains
1. Harvested Products	-121	NO	-121	NO	-85	NO
2. Biodiversity	-54	NO	-11	NO	-12	NO
3. Aesthetic Values	-299	NO	(+)49	YES	(+)79	YES
4. Recreation	(+)108	YES	(+)154	YES	(+)228	YES
5. Water Quality Regulation	-158	NO	-25	NO	(+)72	YES
6. Flood Risk Regulation	-30	NO	-1	NO	(+)19	YES
7. Air Quality Regulation	-44	NO	(+)28	YES	(+)46	YES
8. Local Climate Regulation	-76	NO	(+)180	YES	(+)176	YES
9. Global Climate Regulation	(+)31	YES	(+)61	YES	(+)65	YES
10. Soil Contamination	0	NO	0	NO	0	NO
Natural Capital Net-Gains (number of services achieving net-gain)		2 / 10		5 / 10		7 / 10

Table 2: NC Impact Scores and NC Net-gains for every ES analysed for the 3 different scenarios. (Source: NCPT)

As seen in Table 2, only two ES, Recreation and Global Climate Regulation, achieve NC net-gain for Scenario 1. The positive score achieved in Recreation in this scenario is easily explained because the Waterfront Development Plan site is currently inaccessible greenspace and the new urban design will directly provide new leisure and outdoor activity space to citizens. Regarding Scenario 2, Table 2 reveals that five ES achieve the NC net-gain. This indicates a significant improvement compared to Scenario 1, but there are still some ES in negative values.

Finally, in Scenario 3 most ES are positive and achieve NC net-gains. Harvested Products and Biodiversity are now the only ES with negative scores, although this is almost certainly due to the limitations discussed of the NCPT. Hence, it is seen that "gardens" (in this case understood as BGI) have a negative impact on biodiversity (compared to "poor grassland"). Recreation again has the highest positive score. This can be explained firstly because the space was before inaccessible and, secondly, because there is an increase in green and blue space in this third urban design. As mentioned in Section 2.2, these scores are based only on the design aspect, although future studies on system operation will be conducted too.

3.1 Need for further methodological improvements

The analysis presented in previous sections, based on the TMWDP area and using the NCPT and QGIS tools, showed that the NCPT does not adequately account for important land uses to evaluate the benefits of BGI. For instance, the land use named "gardens" was introduced as the only form of BGI, but this generated negative scores of Biodiversity.

Therefore, it is suggested that new BGI typologies should be introduced in the NCPT land uses, for instance: "Permeable paving", "Detention basins", "Retention ponds", "Buildings with rainwater harvesting" or "Swales". It would also be useful to differentiate between "intensive green roofs" (deeper substrate and shrubby vegetation or even trees) and, "extensive green roofs" (thin layer of soil medium and plants like succulents, grasses or other low maintenance, low growing vegetation), as they might affect the final environmental performance of the buildings [14] . Additionally, "Buildings – area covered with green roof" and "Buildings - green walls" land areas should differentiate three different levels of density (high, medium and low). All of this will definitely deliver new and more accurate scores.

Finally, the tool is also lacking a systems thinking approach because it calculates each ES independently without considering interconnections between the three UIS elements (land, housing and water) presented in Figure 1. For all these reasons and the need for monetary valuation, a prototype for an Integrated Modelling Tool is introduced next.

3.2 New Integrated Modelling Tool

B£ST (Benefits Estimation Tool; CIRIA, 2019) is a tool that provides an estimation of the profits that BGI can generate from an economic perspective; however, it also presents some limitations, such as not including sustainable building valuation side. A new Integrated Modelling Tool (IMT) which solves all the limitations presented in the NCPT and B£ST, and also links their numerical results with a spatial representation of the development, is proposed. It will improve the vision and accuracy for suitable sustainable urban design solutions and enable more collaboration between urban design stakeholders. See the software architecture diagram of this Integrated Modelling Tool (IMT) and its functionality in Figure 7.

Both the NCPT and B£ST are based on spreadsheet interface and the IMT will act as a software wrapper with Python code, enabling the user to design a new urban development layout and relate its spatial representation with ES assessment and monetary prediction. The outputs of the tool will ultimately be compared against approved certification criteria, such as BREEAM Communities or LEED-ND.

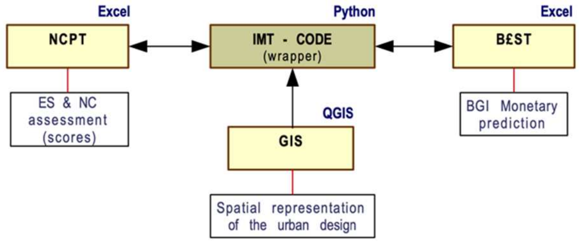

Figure 7: Integrated Modelling Tool (IMT) diagram to understand the software architecture of the prototype.

4. DISCUSSION

London needs to cope with its increasing housing demand to fulfil the expanding economic and social interests, but at the same time it must preserve its natural environment in order to be resilient and adapted to future climate change impacts. Its built environment should provide healthy and secure living-conditions to future generations and considerably reduce the risk of natural catastrophes, such as flooding and droughts. Sustainable urban development is considered crucial to tackle these stresses and its different types of sustainability assessment are still not sufficiently understood.

UIS (Urban Infrastructure Systems) are an interconnected entity and one of the best indicators of their functionality and impact into the environment is the evaluation of UES (Urban Ecosystem Services). This work starts from a systems approach concept in order to define a novel assessment framework for new urban developments, which has been initially outlined in Figure 1. The future steps should improve and redefine this framework and provide a quantitative evidence for optimal urban design solutions. This will require studying BGI and its multiple benefits, as well as the effects of urban form and vegetation within the context of Urban Ecosystem Services (UES) and Urban Natural Capital (UNC).

4. CONCLUSION

Urban Natural Capital (UNC) assessment is crucial to analyse the impacts of new urban developments on the environment. It will help housing developers, urban planners and policy-makers to make better decisions, especially at the early stages of the design. However, initial studies that combine NCPT numerical results with QGIS maps have shown that these tools are still lacking some important functionalities and there remains a need for a revised method. Hence, the next steps in this research work will focused on developing a new and integrated modelling tool for Urban Natural Capital (UNC) and Urban Ecosystem Services (UES) assessment in order to provide more accurate and valuable results, all mapped from an overarching systems thinking perspective.

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REFERENCES

1. Mijic, A. and Brown, K. (2019). Integrating Green and Blue Spaces Into Our Cities: Making It Happen. Grantham Institute Briefing Paper, No 30. Imperial College London.
2. United Nations (2014). World urbanization prospects: The 2014 revision, highlights. Population division, United Nations.
3. Greater London Authority (GLA), (2019). The Draft London Plan. Consolidated changes version – Clean July 2019. Report.
4. Clark, J., et al. (Policy Connect) (2018). Bricks & Water: A Plan of Action for Building Homes and Managing Water in England. Westminster Sustainable Business Forum.
5. Ford, A., et al. (2019). A multi-scale urban integrated assessment framework for climate change studies: A flooding application. *Computers, Environment and Urban Systems* 75.
6. Inostroza, L. and F. De la Barrera (2019). Ecosystem Services and Urbanisation. A Spatially Explicit Assessment in Upper Silesia, Central Europe. IOP Conference Series: Mater. Sci. Eng. 471 092028.
7. Lawton, J., et al. (2010). Making Space for Nature: A review of England's Wildlife Sites and Ecological Network. Report to Defra, UK.
8. Raymond, C. M., et al. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy* 77: 15–24.
9. Keeler, B. L., et al. (2019). Social-ecological and technological factors moderate the value of urban nature. Review Article. *Nature Sustainability* 2(1): 29–38.
10. Gómez-Baggethun, E. and D. N. Barton (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics* 86: 235–245.
11. Mace, G. M., et al. (2015). Towards a risk register for natural capital. Review article. *Journal of Applied Ecology* 2015, 52, 641–653.
12. Maksimovic, C.; Bozovic, R.; Mijic, A.; Suter, I; Van Reeuwijk, M. (2017). Blue Green Solutions. A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development. Imperial College London.
13. Ahmadian, E., et al. (2019). Sustainable cities: The relationships between urban built forms and density indicators. *Cities*: 95.
14. Oke, T., Mills, G., Christen, A., & Voogt, J. (2017). Urban Climates. Cambridge, Cambridge University Pres. ISBN: 9781107429536